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AN EXPERIMENT IN AURAL DETECTION OF HELICOPTERS

By

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December 1973

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-71-C-0065
BOEING VERTOL COMPANY
PHILADELPHIA, PENNSYLVANIA

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This report was prepared by Boeing-Vertol Company under the terms of Contract DAAJ02-71-C-0065. It presents the results of a field test designed to evaluate an analytical method for predicting detectability of helicopter noise (USAAMRDL TR 71-33, "Helicopter Aural Detectability").

This study, in keeping within the planned level of effort, was restrictive in that only one helicopter type, speed, and altitude condition were investigated, but this permitted examination of a variety of background noise conditions. As a result of this study, the rate of occurrence of detection by a group of observers was determined for octave bands of noise and the associated noise levels.

This report has been reviewed by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, and is published for dissemination of information and appropriate application.

The technical monitor for this contract was Mr. Bill W. Scruggs, Jr., Military Operations Technology Division.

TASK 1F162205AA5202
Contract DAAJ02-71-C-0065
USAAMRDL Technical Report 73-50
December 1973

AN EXPERIMENT IN AURAL DETECTION OF HELICOPTERS

Final Report

Prepared By

L. Hartman
H. Sternfeld

Boeing Vertol Company
Philadelphia, Pennsylvania

for

EUSTIS DIRECTORATE
U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

SUMMARY

The current accepted method, as reported in USAAMRDL TR 71-33 (Reference 2), for predicting aural detection of helicopters was developed under laboratory conditions, and its accuracy has not been verified with actual field measurements. The purpose of the program described in this report was to conduct an experiment to evaluate this analytical prediction method. To accomplish this task, a test program was conducted using a light commercial helicopter, six test observers, and various ambient noises. Aircraft and ambient noises, aircraft location, and indication of subject detection were recorded. The test results were then compared with analytically predicted results using Reference 2.

Analyses of the 228 detection occurrences showed that the helicopter was never detected at the Reference 2 predicted detection levels. Extrapolation of the test data to these levels results in an extremely low probability (less than 1%) that detection can occur. In general, most of the detections occurred at the lower main rotor harmonic frequencies; hence for these low frequencies Reference 2 appears extremely conservative.

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FOREWORD

The work reported herein was performed by Boeing Vertol Company, Acoustics Department, under Phase V of Contract DAAJ02-71-C-0065 for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. The work was carried out under the technical cognizance of Mr. Bill W. Scruggs of the USAAMRDL Staff. The work was authorized by DA Task 1F162205AA5202.

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1.0 INTRODUCTION

In recent years, several programs have been conducted which were directed at obtaining a better understanding of aural detection of helicopters.

In one program, conducted by the U.S. Army Combat Developments Command (Reference 1), aural and visual detection times were compared for three helicopters performing "nap of the earth" flying over various terrains. For that program no acoustical data was obtained at the observer's location which could be used for direct correlation purposes.

In another program, the Eustis Directorate, USAAMRDL, sponsored development of an analytical procedure for predicting aural detection of helicopters (Reference 2). The program used laboratory testing and tape-recorded signals but was not verified by actual field testing.

In 1971 the Boeing Vertol Company conducted a company-funded program on the same subject (Reference 3). This program also was in a laboratory environment but differed from the Reference 2 program with respect to the method of producing the test signals, the types of ambient noise, and the method of establishing detection by the test subject.

The differences in conclusions drawn from the results of the latter two programs appear to be significant with respect to the difference in frequency which caused detection and also in conclusions reached between the relative levels of the ambient and signal at detection. The differences here may lie in the types of ambient noise used and/or the method used to establish detection, since the Reference 2 program permitted the test subjects to adjust and readjust the noise, while in the Boeing program the subject had no control over either the level or the timing of the aircraft sounds.

Although all of the above-mentioned work has contributed to an understanding of aural detection of helicopters, it was evident that a need existed for a program which used an actual aircraft with simultaneous measurements of aircraft noise, ambient noise, and aircraft location at the point of aural detection. To achieve this objective and thereby evaluate the existing analytical prediction methods of detection, a test program was conducted using a light commercial helicopter, six test observers, and various ambient noises while simultaneously recording aircraft and ambient noise, aircraft location, and indications of subject detection.

2.0 TEST METHOD

2.1 GENERAL APPROACH

The purpose of this program was to conduct an experiment in the aural detection of helicopters in order to evaluate analytical prediction methods. The test was designed not only to provide a comparison of predicted and measured detection distances, but also to provide insight into the relationship between aircraft and ambient sound pressure levels at detection, and perhaps a more useful definition of detection.

The test approach is illustrated in Figure 1. A general description of the test methodology follows.

The helicopter was flown at 90 miles per hour and 200 feet altitude past a group of test observers. The observers, who were visually, but not acoustically, screened from the aircraft, indicated when they detected the helicopter by actuating electrical indicating devices. Test ambient noise around the observers was supplied and controlled by suitable loudspeakers, tape playbacks, and amplifiers. Two low-frequency microphones were used to record the noise; one (located with the observers) sensed both the test ambient and helicopter noise, while the other (located 460 feet from the observers) sensed the helicopter with the natural ambient at the test site, thereby giving improved definition of the helicopter noise. The differences between the helicopter and the test ambient sound pressure levels were then compared to the Reference 2 (Appendix IV) predicted difference of -5 db. This method eliminated the variables of aircraft noise generation and propagation and evaluated the noise at the observer in consonance with Reference 2 techniques.

2.2 INDICATION OF DETECTION

Each observer was given an electrical switch box, Figure 2, with two switch positions (in addition to the "off" position) for indicating two levels of aircraft detection. The first level of detection occurred when an observer thought that he heard a helicopter (even if he were not certain). The observer was instructed to select switch position "maybe" at this level. The second level of detection occurred when the observer was absolutely sure that he had detected the helicopter. At this level he was instructed to select switch position "yes". By conducting the test program in this manner, it was possible to differentiate between a threshold detection and the distance at which an individual might be expected to initiate a more definite action.

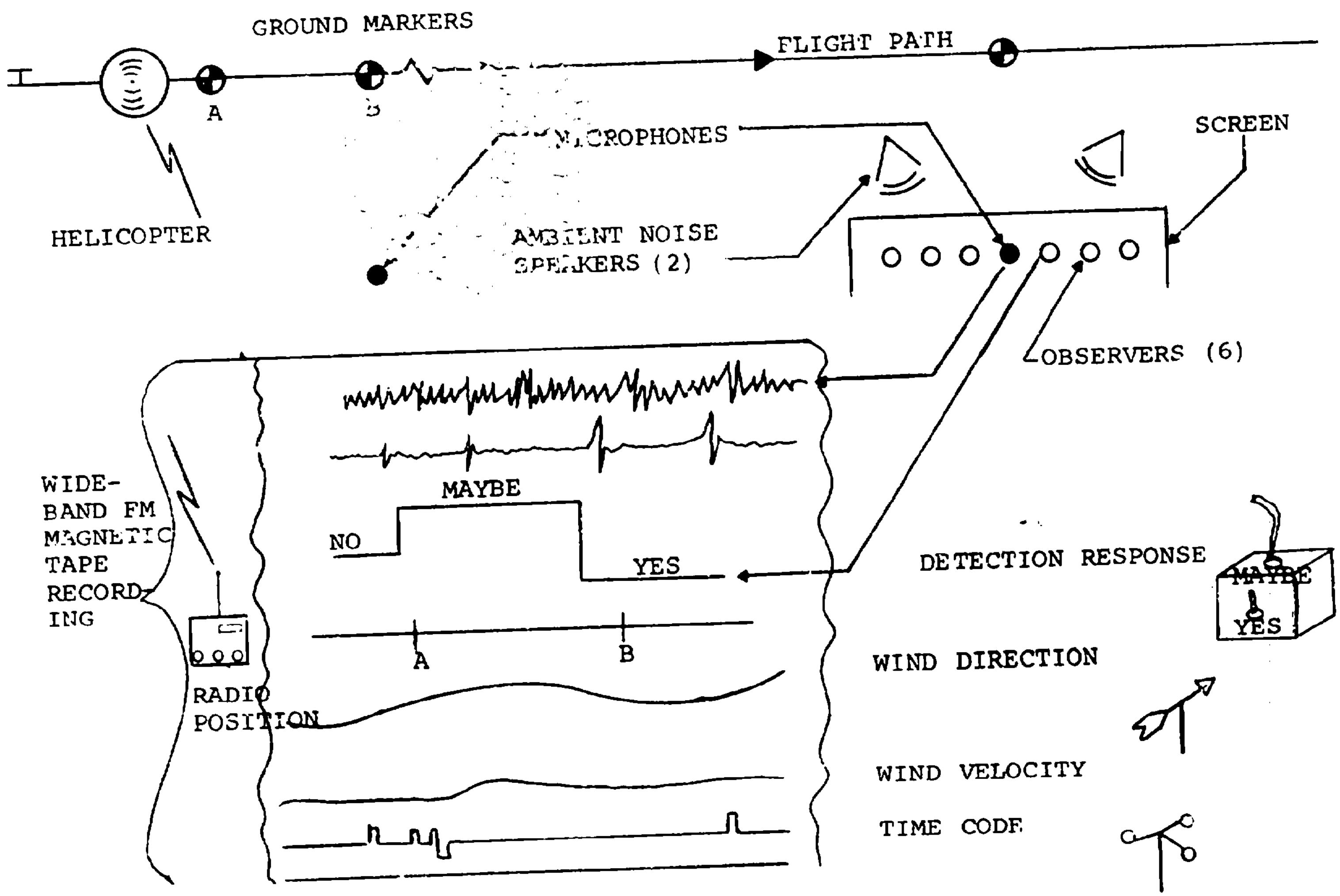


Figure 1. Schematic Diagram of Test Method.

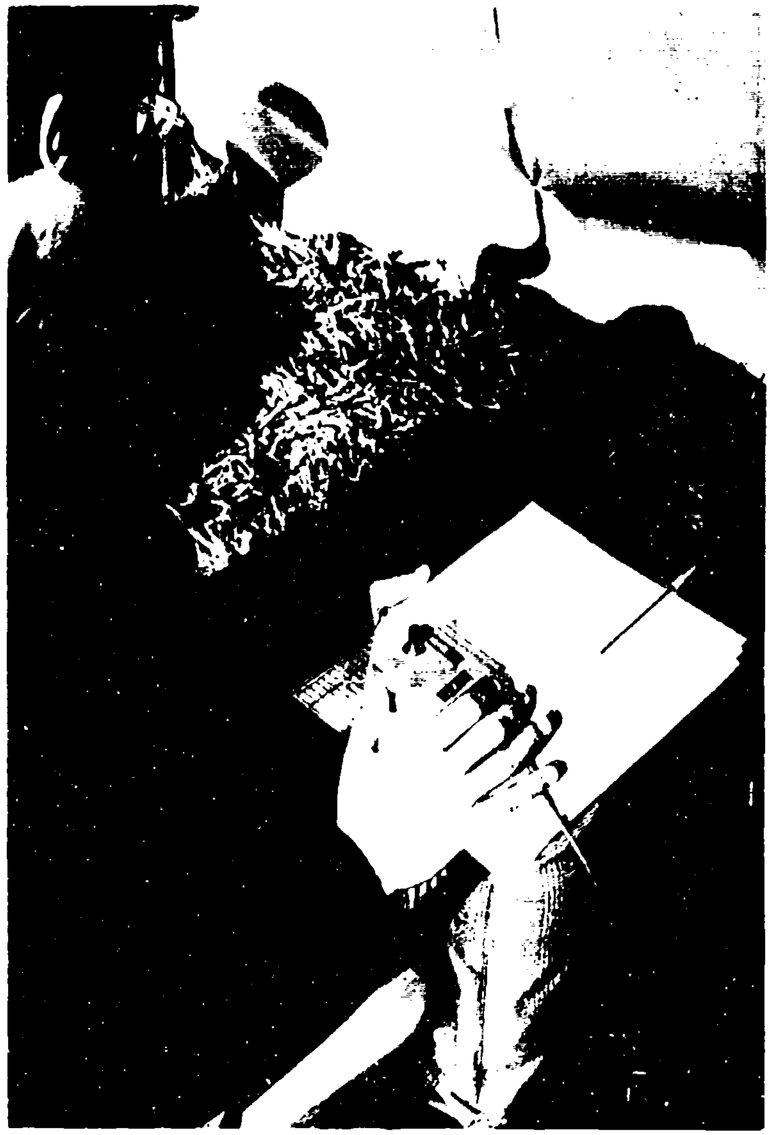


Figure 2. Observer With Detection Indicating Switch.

2.3 TEST OBSERVERS

The six observers selected for the test were male employees of Boeing Vertol Company, and all were under 40 years of age. Each observer was given an audiogram by the Division Medical Department. The results of these audiograms indicated that the six observers had no medically defined hearing loss.

Prior to conduct of the test, each observer was given a copy of written instructions which described the purpose of the test and the specific instructions to be followed for each run. These instructions, as shown in Appendix I, were also read orally to the group by a test director just prior to the start of the first test run.

In addition to the specified instructions, each observer was given a set of cards to record any significant occurrence which may have affected him during a run. One member of the group was assigned the role of team leader. If any of the observers needed a break during the testing, the leader would inform the test director. He would also inform the test director of any occurrences during a particular run which may have affected the observer's decisions. These runs were then repeated.

2.4 TEST SITE

The preliminary and final test programs were conducted over a partially wooded area in Chester County, Pennsylvania. Figure 3 shows the terrain at the test site, and it can be considered typical of the surrounding terrain over which the helicopter flew. The flight path of the helicopter over the test site is shown in Figure 4. The distance between Position 1 and the test observers was such that the helicopter was inaudible to the observers regardless of the ambient noise. In addition to Positions 1 and 2, which were paved roads used as ground markers for providing aircraft location and ground speed data, two 4-by 4-foot plywood markers, Positions 3 and 4, were placed 400 feet apart and at a 200-foot sideline distance to the test observers. These markers enabled the pilot to fly the helicopter at the desired 200-foot sideline distance to the observers and thus also provided for repeatability in the chosen flight path.

The six test observers were located 200 feet to the right side of the flight path and were seated behind a screened area (20 by 6 feet, Figure 5) which prevented them from seeing the approaching helicopter. The screening material consisted of two layers of porous woven glass cloth which was of low flow resistance and therefore was acoustically transparent.

Figure 3. Terrain at the Test Site.

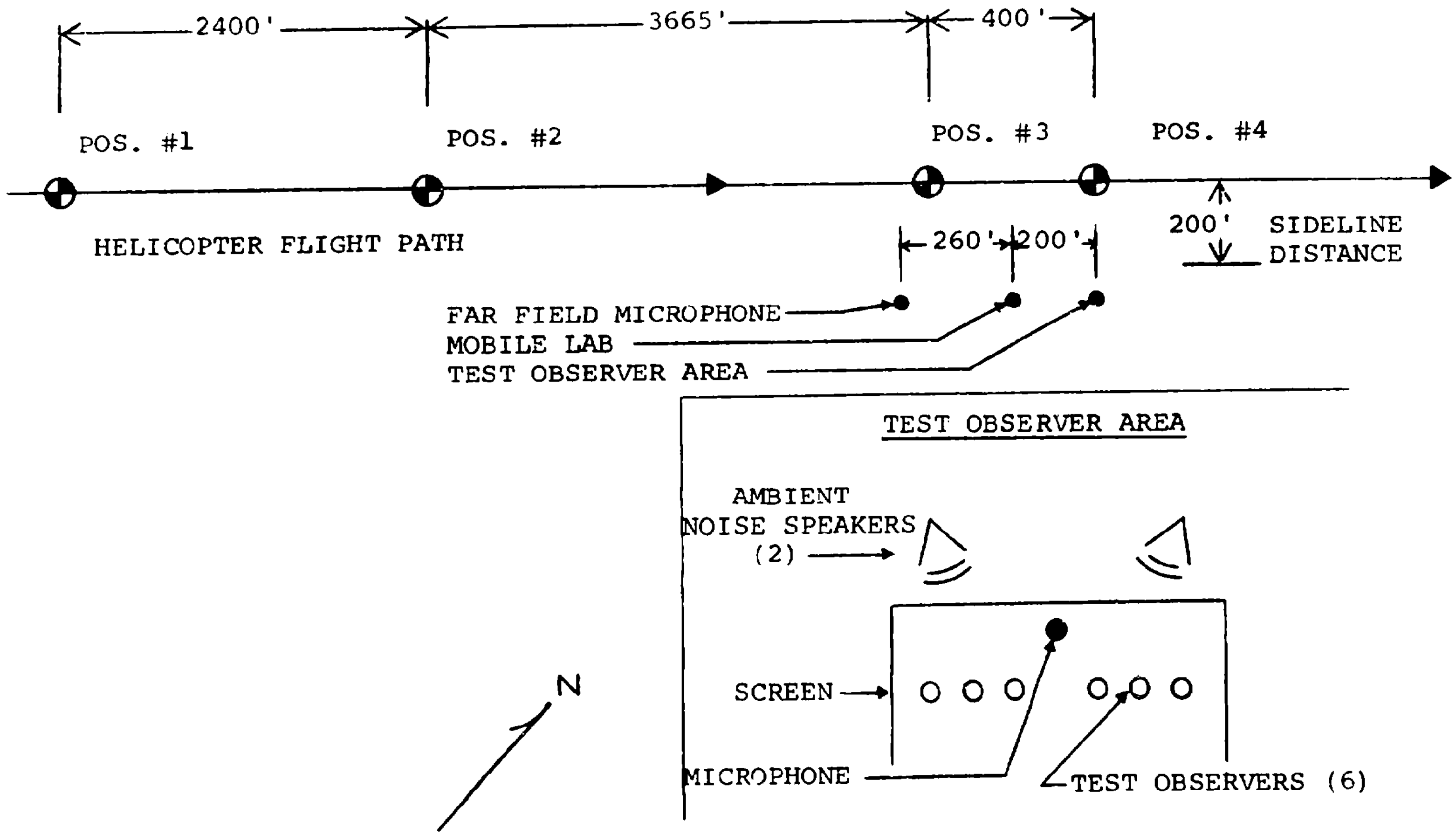


Figure 4. Diagram of Test Site.

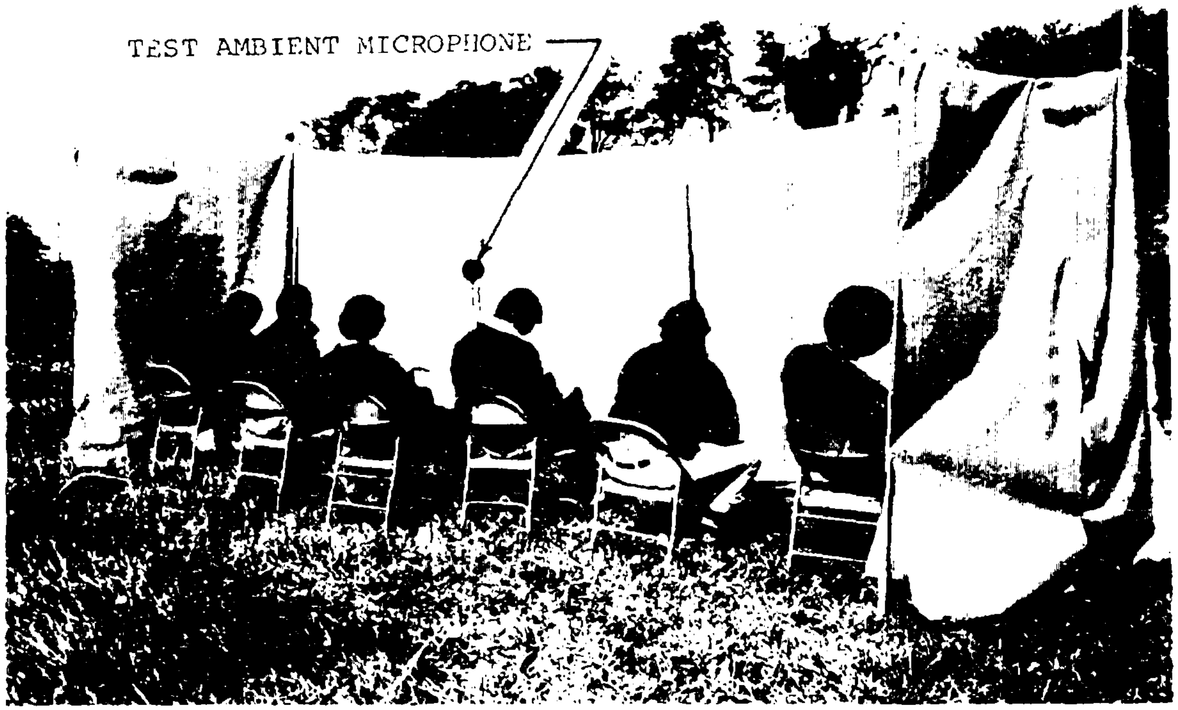


Figure 5. Observers Seated Behind Screened Area.

Two microphones were used during the test program. One microphone was located behind the screened area and at an equivalent ear level height, where it sensed both the generated ambient noise and the helicopter noise. The second microphone was located at the same sideline distance to the flight path (200 feet) but at a distance of 460 feet from the loudspeakers so that it sensed aircraft noise only.

The mobile laboratory was positioned between the far-field microphone and the test observer area.

2.5 TEST AIRCRAFT

The test aircraft was a Bell 206A Jetranger Commercial helicopter. This helicopter was chosen for testing because it generates both a main and a tail rotor noise signature and because it represents, in its military version, the Army's OH-58. It was flown in standard configuration with a crew of two (pilot and engineering observer).

2.6 INSTRUMENTATION

The Boeing Vertol Mobile Acoustical Laboratory, Figure 6, was used to house and power the instrumentation in the field. A 14-channel wide-band, FM tape recording system, Ampex AR 200, was used to record the following data at 30 inches/second tape speed:

1. Detection indicators; six switch boxes with two modes of indication.

2. Sound pressure level; two low-frequency Photocon microphones, Model 474, used in conjunction with Type DG605, Dynagage signal conditioning units.

3. Wind direction.

4. Wind velocity.

5. Aircraft location by radio communication from the aircraft.

6. Time code.

7. Voice identification.

Figure 6. Mobile Acoustical Laboratory.

All data were continuously recorded from initiation of the run (aircraft inaudible to the test observers) to completion (the aircraft passed over position 4 and all six observers detected the aircraft).

The following equipment was installed in the mobile laboratory and was used to produce and monitor the ambient noise level:

1. Random Noise Generator - Type 1390B
   General Radio Company

2. Tape Recorder - Nagra IIIB
   Kuldelski

3. Mixer Amplifier - Type 68
   Shure

4. Spectrum Shaper - Tracor Model 318A
   Allison Laboratories

5. Power Amplifier - Type MC75
   McIntosh

6. Loudspeakers - Model A7
   Altec Company

7. Graphic Level Recorder - Type 2305
   Brüel & Kjaer

8. Audio Frequency Spectrometer - Type 2112
   Brüel & Kjaer

A block diagram of the instrumentation recording system and ambient noise producing equipment is shown in Figure 7.

2.7 SYSTEM CALIBRATION

Calibration of the test ambient and the aircraft data microphones and recording system was performed in the acoustical laboratory using an electrostatic actuator and signal generator. The overall system response was obtained for a frequency range of 15 Hz to 14 kHz, as shown in Figure 8. Due to the limiting capability of the signal calibrator, the system could not be calibrated for frequencies below 15 Hz. This limitation, however, did not invalidate the test results. The overall specification limits of the FM recording system with a photocon microphone show a response down to 2 Hz with a ± 2 dB accuracy. In addition, the data recorded at these low frequencies did not set detection; in fact, all of this low-frequency data fell 10 to 30 dB below the absolute threshold of audibility.

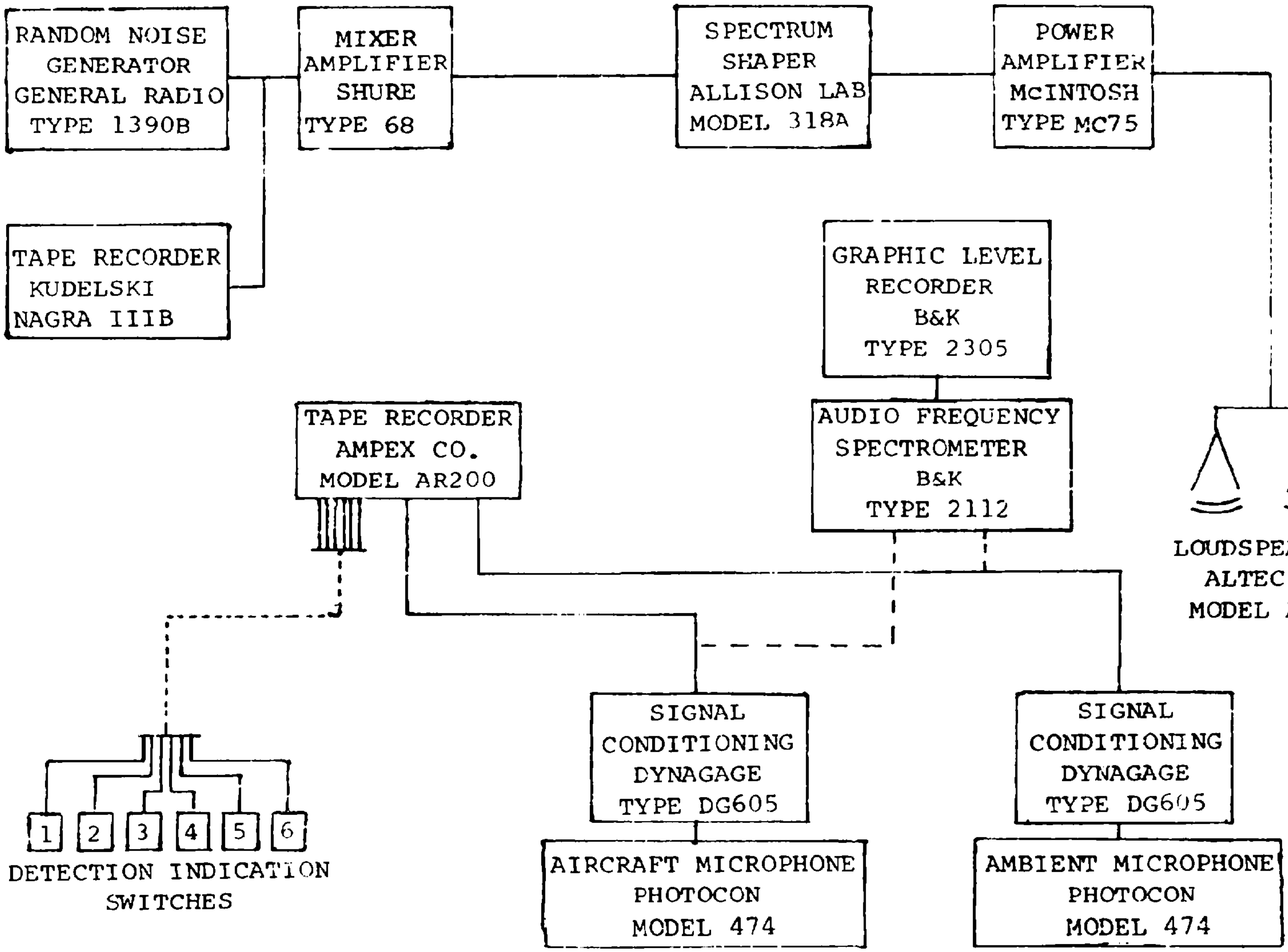
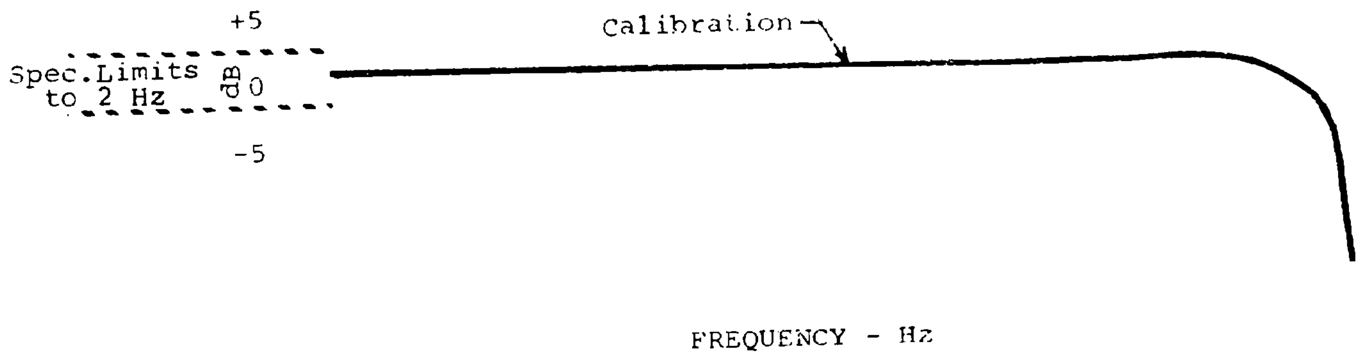
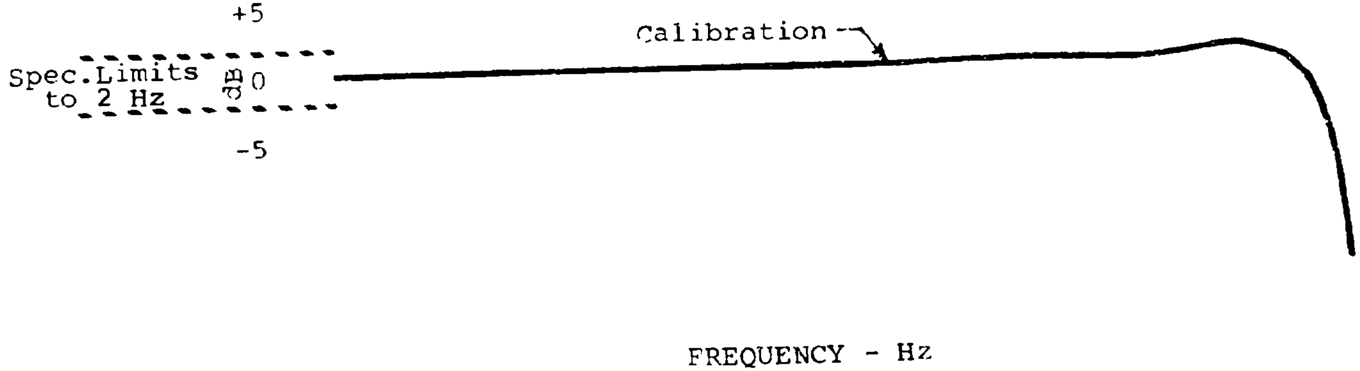


Figure 7. Block Diagram of Instrumentation Recording System and Ambient Noise Producing Equipment.



(a) AMBIENT MICROPHONE



(b) AIRCRAFT MICROPHONE

Figure 8. Microphone System Frequency Response.

At the test site and prior to the start of the test, the microphones were also calibrated using a Brüel and Kjaer Type 4230 calibrator with a 94-dB, 1000-Hz signal.

2.8 TEST PROCEDURE

Prior to the start of each test run, the desired ambient noise was selected and played over the two loudspeakers at the test observer location. During this period, the helicopter was beginning its approach to position 1 (at 200 feet altitude). At approximately one-half mile from position 1, a position report was given by the observer onboard the aircraft; at this time, the data tape was started, the observers were notified that the run was beginning, and they were instructed to remain silent.

As the aircraft passed over the ground markers, 1-4, the observer in the aircraft transmitted the aircraft position. This radio transmission was recorded on the magnetic tape in the mobile lab. During the run, the test observers were detecting the aircraft at the two levels of detection by selection of their switches.

To avoid contamination of the test runs with extraneous noises, an engineer, with radio communication to the helicopter, was positioned in the field and monitored the test area during each run. Runs which were significantly affected by other noises (i.e., transient aircraft, etc.) were repeated.

The mobile acoustical laboratory data monitoring capability ensured that the test program was being conducted as planned. Prior to the run, the microphone in the vicinity of the test observers was used to transmit the ambient noise to the lab, where it was analyzed on the Brüel and Kjaer level recorder and audio frequency spectrometer for the desired level and spectrum shape. During the run, the level recorder was used to monitor the aircraft noise signature and also to obtain preliminary detection data. The test observer detection switches would simultaneously illuminate a response light in the laboratory (Figure 9). By monitoring these lights, an average detection time could be determined. By marking the graphic level recorder at the average detection time for observers' yes response and also at the time when the helicopter passed over the subjects, an approximate detection distance could be obtained. It was therefore possible to select ambient noise levels that would permit detection over a wide range of distances.

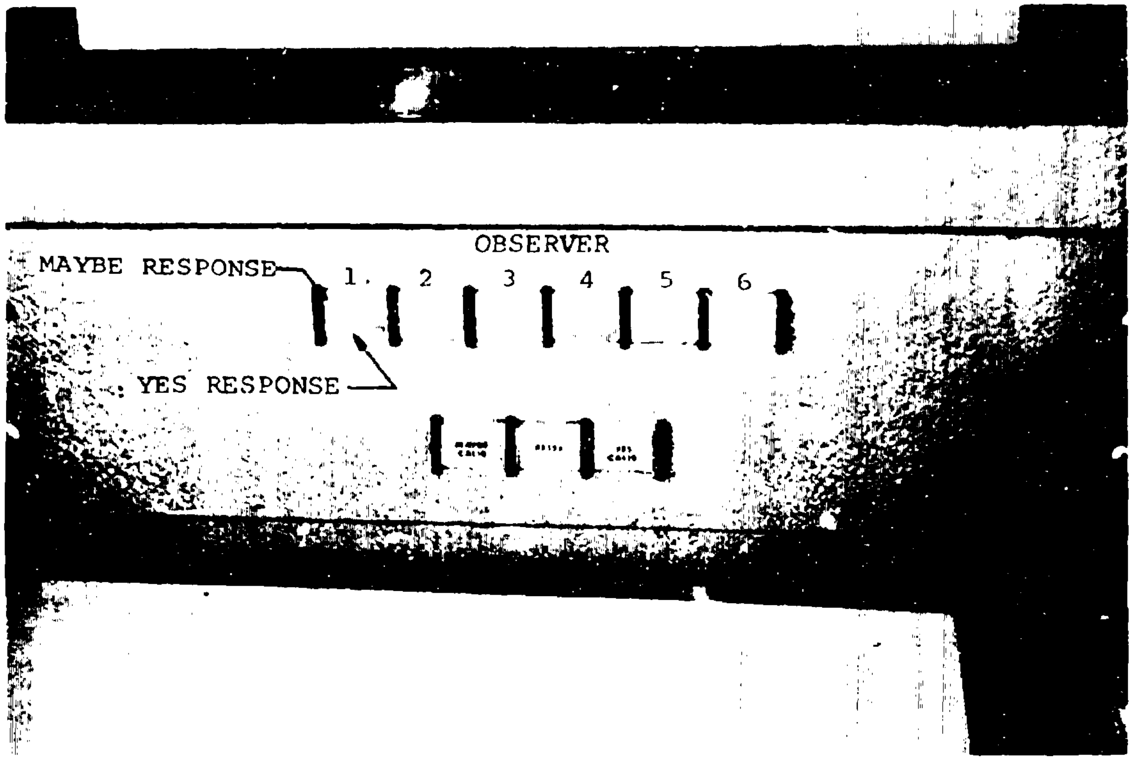


Figure 9. Mobile Laboratory Detection Monitoring Lights.

2.9 PRELIMINARY TEST

In order to obtain the maximum information within the program limitations, the final selection of ambient noises was based on a preliminary test, which was conducted on 25 September 1972 using the test aircraft and site with three observers.

The purpose of this phase of the test program was fourfold:

1. Determination of the maximum detection distance with the natural ambient, ensuring that the aircraft would start the runs at a distance far enough away to be inaudible to the observers.
2. Determination of the airspeed to be used.
3. Selection of the actual levels of ambient noise to ensure an adequate variation in detection distances.
4. Selection of gain settings for the recording system to ensure optimum recording levels.

The entire test system as described in this report was set up at the test site. However, three observers were used for detection in lieu of the six observers used during the final test. To accomplish the test objectives, 18 runs were conducted at various airspeeds and ambient settings. The on-line monitoring capability of the mobile laboratory as described in Sections 2.6 and 2.8 of this report ensured adequate determination that the preliminary test objectives were met and thereby eliminated the requirement for extensive post-test data analysis. For this reason, none of the preliminary test microphone and detection data is presented in this report. However, a list of the preliminary test conditions is contained in Table I.

Runs 1 through 3 were conducted with the natural ambient of the test site at airspeeds of 60, 90 and 120 mph, respectively. During each of these runs, the aircraft was detected within the selected course, ensuring an adequate starting distance from the observers. Runs 4 through 9 were conducted at three levels of ambient noise with flat and sloped spectrum shapes. The low level was selected such that it was slightly higher than the natural ambient in order to provide a controlled low ambient (50-55 maximum dB in any octave band). To reduce the possibility of introduction of a hearing threshold shift, the high-level ambient was limited to 80 dB. The sound pressure level of the medium-level ambient was set in the dB range of 55-65.

Run No.	Test Ambient Condition	Test Ambient Level	Test Ambient Octave Bands Removed (Hz)	Airspeed mph	Winds Dir/Speed (deg/mph)
1	Natural	N/A	None	60	030/3-4
2	Natural	N/A	None	90	090/2
3	Natural	N/A	None	120	040/5
4	Flat	Low	None	90	100/5
5	Flat	High	None	90	090/5
6	Flat	Medium	None	90	090/4
7	Sloped	Low	None	90	090/4
8	Sloped	High	None	90	090/4
9	Sloped	Medium	None	90	135/2
10	Flat	Medium	None	90	090/3
11	Flat	Medium	31.5	90	090/5
12	Flat	Medium	63	90	115/2
13	Flat	Medium	125	90	090/5
14	Flat	Medium	250	90	070/7
15	Flat	Medium	500	90	090/6
16	Flat	Medium	1000	90	090/5
17	Modulated	High	None	90	090/3
18	Steady	Medium	None	90	090/3

Table: TABLE I. PRELIMINARY TEST CONDITIONS*

* At 200 ft above the terrain, the outside air temperature was +20°C, and the air conditions were assessed as smooth.

These three levels provided for a wide range of detection distances to be tested. From the three airspeeds flown, it was determined that the helicopter noise signature did not vary significantly with increased airspeed. Ninety mph was selected as the optimum airspeed as it provided a reasonable time to fly the course without excessive fuel consumption. Runs 11 through 16 were used to check out the effects of removal of specific octave bands from the spectrum.

2.10 FINAL TEST

In the final test, which was conducted on 2 October 1972, 41 test runs were successfully conducted using six observers and 27 various ambient noise conditions. Since the wind velocity during the entire test was extremely low, generally ranging from 2 to 6 mph, its effect on the noise data was negligible, thereby eliminating the need for an upwind and downwind approach of the helicopter. A check on repeatability of observer response was accomplished by repetition of selected conditions during the test.

Table II contains a complete list of the test runs. The test procedure for each of these runs was the same as that described in Section 2.8.

2.11 DATA REDUCTION

The following procedure was used to reduce and analyze the data obtained during the test program:

1. All data from both microphones was reduced to give a 1/3 octave band spectrum every 1/2 second during each run. An automated system, available at the Boeing Commercial Airplane Company, was used.

2. The time of each individual detection observation was determined by comparing the signal at each observer's response indication with the time code on the magnetic tape.

3. To permit direct correlation of the aircraft sound pressure level as measured by the remote microphone with the aircraft sound pressure level as detected by the observers, a time correction was necessary. The requirement for this correction is illustrated in Figure 10.

TABLE II. FINAL TEST CONDITIONS*				
Run No.	Test Ambient Condition	Test Ambient Level	Test Ambient Octave Bands Removed (Hz)	Winds Dir/Speed (deg/mph)
1	Natural	N/A	None	235/2
2	Natural	N/A	None	235/2
3	Natural	N/A	None	235/2
4	Flat	Low	None	235/2
5	Flat	High	None	235/2
6	Flat	Medium	None	235/2
7	Flat	Medium	31.5	235/2.5
8	Flat	Medium	63	205/2
9	Flat	Medium	125	205/2
10	Flat	Medium	250	205/2
11	Flat	Medium	500	205/2
12	Flat	Medium	1000	205/2
13	Flat	Medium	2000	135/2
14	Flat	Medium	4000	135/2.5
15	Flat	Medium	None	090/3
16	Sloped	High	None	070/3
17	Sloped	Low	None	090/3
18	Sloped	Medium	None	090/2
19	Sloped	Medium	31.5	090/2
20	Sloped	Medium	63	135/5
21	Sloped	Medium	125	205/4
22	Sloped	Medium	250	255/4
23	Sloped	Medium	500	090/5
24	Sloped	Low	None	090/5
25	Sloped	Medium	None	090/6.5
26	Sloped	High	None	090/3
27	Flat	Medium	None	235/4
28	Truck	Low	None	0 /3
29	Truck	Medium	None	022/2
30	Truck	Low	None	180/2
31	Truck	High	None	180/2.5
32	Flat	Medium	None	135/5
33	Steady	Medium	None	235/3
34	Modulated-Low Rate	Medium	None	235/3

TABLE II - Continued

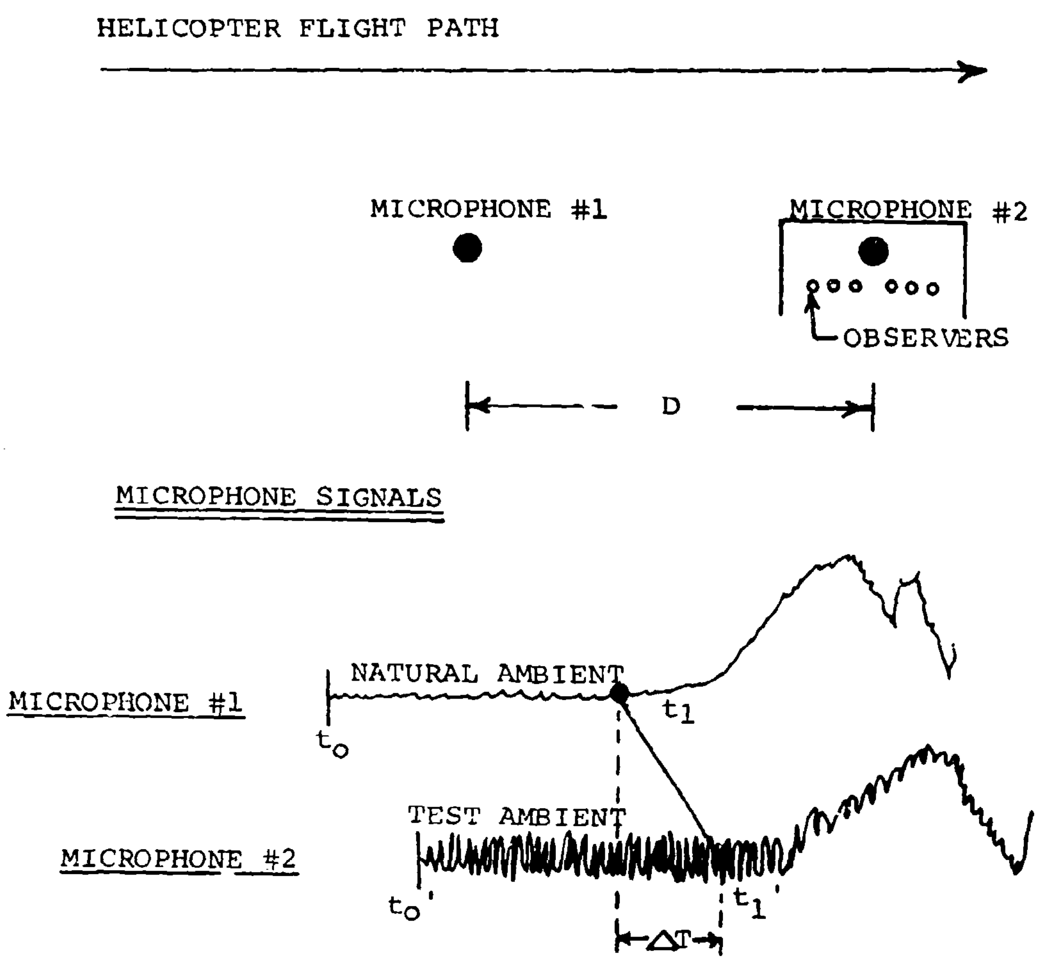
Run No.	Test Ambient Condition	Test Ambient Level	Test Ambient Octave Bands Removed (Hz)	Winds Dir/Speed (deg/mph)
35	Modulated-Med Rate	Medium	None	067/6
36	Modulated-High Rate	Medium	None	090/2
37	Modulated-High Rate	Medium	None	270/6
38	Steady	Medium	None	270/6
39	Flat	High	None	135/10
40	Flat	Low	None	135/4
41	Flat	Medium	None	135/6

*At 200 ft. above the terrain, the outside ambient temperature was +15°C and the air conditions were assessed smooth with occasional light turbulence.

4. At the nearest 1/2 second to each detection, the corresponding 1/3 octave band analysis of the aircraft noise was read and the ambient noise at the observers' location was subtracted from it.

5. The 1/3 octave in which the difference between the aircraft and ambient SPL's is greatest is assumed to be responsible for the detection, and the numerical difference in SPL's is that required to separate the aircraft and the ambient noises.

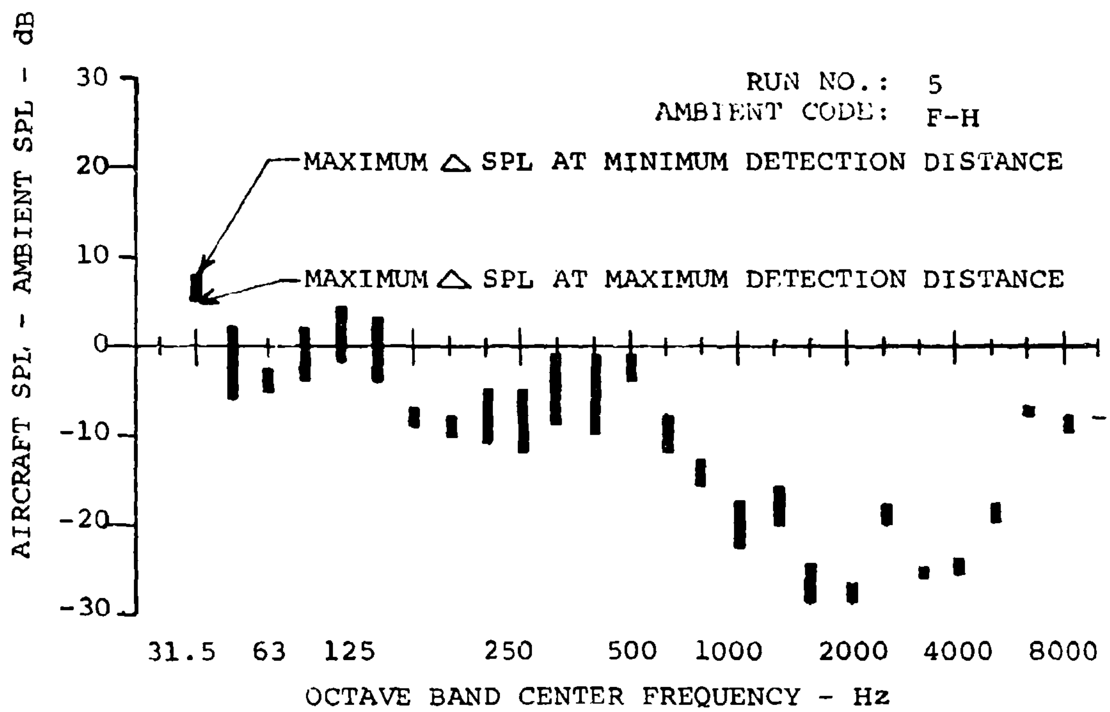
Appendix II presents the detection distances, the test ambient noise spectra and the mean of the aircraft noise spectra (the mean of each bandwidth noise spectra for the minimum and maximum detection distances) for each test run. (Due to data unavailability runs 28, 39 and 40 are not presented.) The numerical differences between these two noise spectra at the minimum and maximum detection distances are presented in Appendix III. Figure 11 contains a sample of the data presented in this appendix.



Δ T = Time required for the helicopter to fly the distance D between the two microphones

When detection occurs at time t_1', the aircraft SPL which the observers detected at their location, would be that sensed by Microphone #1 at time t_1.

Figure 10. Time Correction, Aircraft Microphone Data.



At Each 1/3 Octave Band:

1) The top of the bar represents the difference between the aircraft SPL and the ambient SPL at the time when all six observers detected the helicopter.

2) The bottom of the bar represents the difference between the aircraft SPL and the ambient SPL at the time when the first observer detected the helicopter.

3) The 1/3 octave band where the △ SPL level is greatest, is the detection frequency as described in Reference 2, Appendix IV.

Figure 11. Determination of the Detection Frequency.

3.0 DISCUSSION AND RESULTS

3.1 RELATIONSHIP OF AIRCRAFT AND AMBIENT NOISE AT DETECTION

Reference 2 developed a methodology for the prediction of helicopter aural detection thresholds from measured or estimated parameters, including methods for calculating propagation losses. The primary objective of this test program was to compare the detection threshold of both the test results obtained and the predicted detection threshold using Method B of Reference 2, Appendix IV. According to the results of the Reference 2 tests, the helicopter signal can be detected when its level in any frequency band is above the absolute threshold of audibility and 5 dB below the ambient noise level. By correlating the helicopter position at the time of aural detection with acoustical data measured on the ground, this program eliminates the variables of noise generation and propagation and therefore evaluates the ability to aurally separate the aircraft signal from the ambient noise and any additional processes involved in arriving at a detection decision.

Figure 12 presents the major result of this program in terms of probability of detection as a function of the difference between aircraft and ambient sound pressure levels at the observer. Each point on the plot represents the percentage of the total number of detections which occurred when the difference between the aircraft and ambient sound pressure levels were equal to or less than the ordinate value of the data point. Each separate "yes" detection for each observer and each run was compared with the spectral differences as described in Section 2.11, so that Figure 12 is the cumulative result of 228 detection occurrances.

The closeness to a straight-line fit (on probability paper) of the data shown in Figure 12 indicates a normal distribution which permits valid interpolation and extrapolation

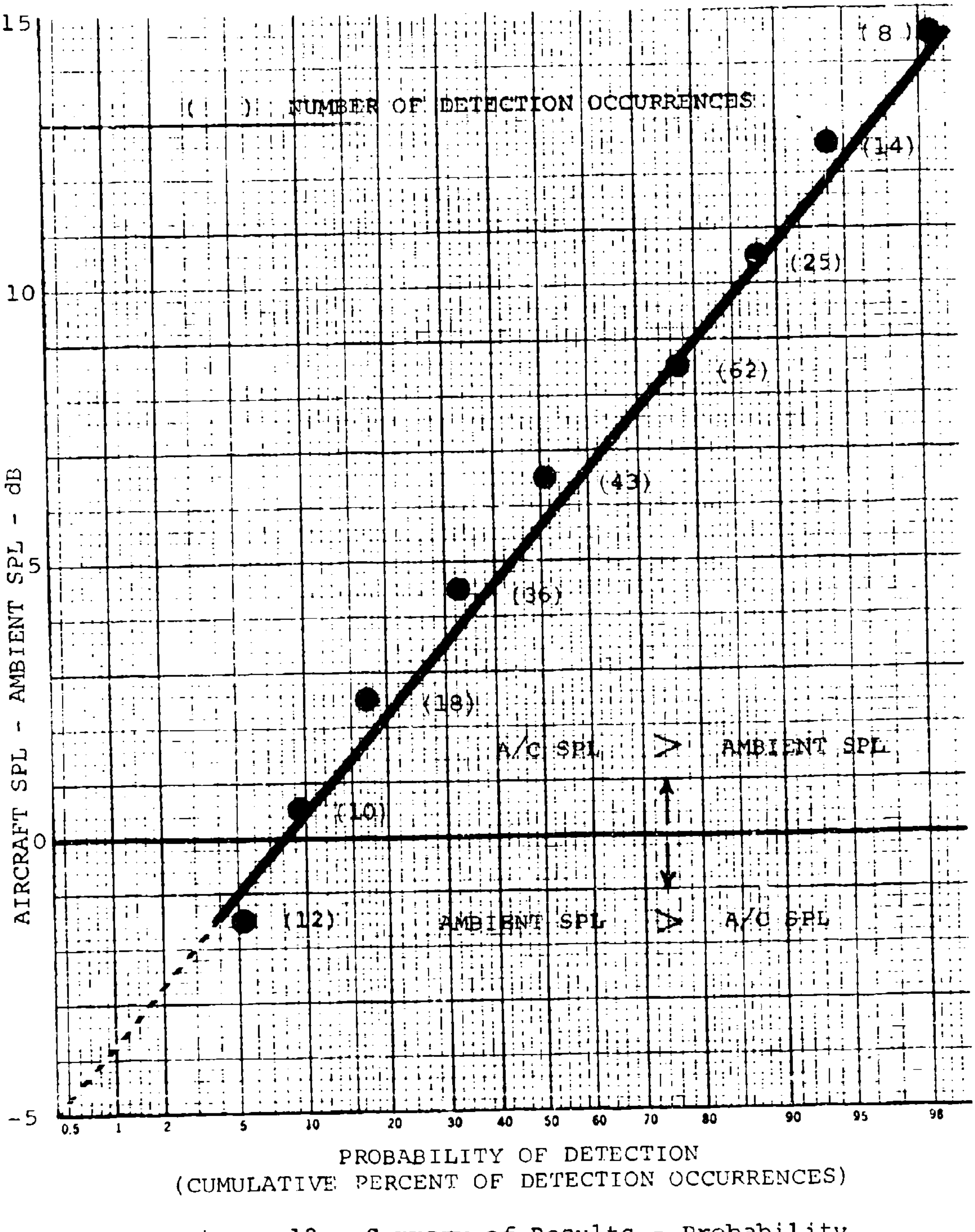


Figure 12. Summary of Results - Probability of Aural Detection.

For example, using this display, to have a 50% probability of definite helicopter detection, the aircraft noise at the detection frequency must be 6 dB above the ambient noise. On the other hand, since no data was measured at a Δ SPL of -5dB, the test results do not in themselves show that detection at this level is possible. However, when extrapolated to this level, the probability of aural detection is 0.5%, or 1 observer out of 200 would be expected to detect the helicopter when its level is 5 dB below the ambient.

3.2 COMPARISON WITH ANALYTICAL PREDICTIONS

The prediction method of Reference 2, Appendix IV, is based on the assumption that detection will take place when the aircraft sound pressure level, at any frequency, reaches a level 5 dB below the ambient noise at that frequency provided that the aircraft noise is above the threshold of hearing.

As can be seen in Figure 12, such an assumption appears to be extremely conservative and, in fact, requires extrapolation of the test data.

The data shown in Figure 12 was derived from the detection data at the time when each observer definitely detected the helicopter. However, as discussed in Section 2.2, the observer also indicated a level of detection at the time when he thought he detected the helicopter but was not certain. Figure 13 shows the relationship of these two levels of detection in terms of helicopter time and distance from the observers. Since the time interval between the uncertain and definite responses is small, the Reference 2 method is not only conservative in prediction of a definite detection distance, but it is as conservative when used to predict a detection threshold.

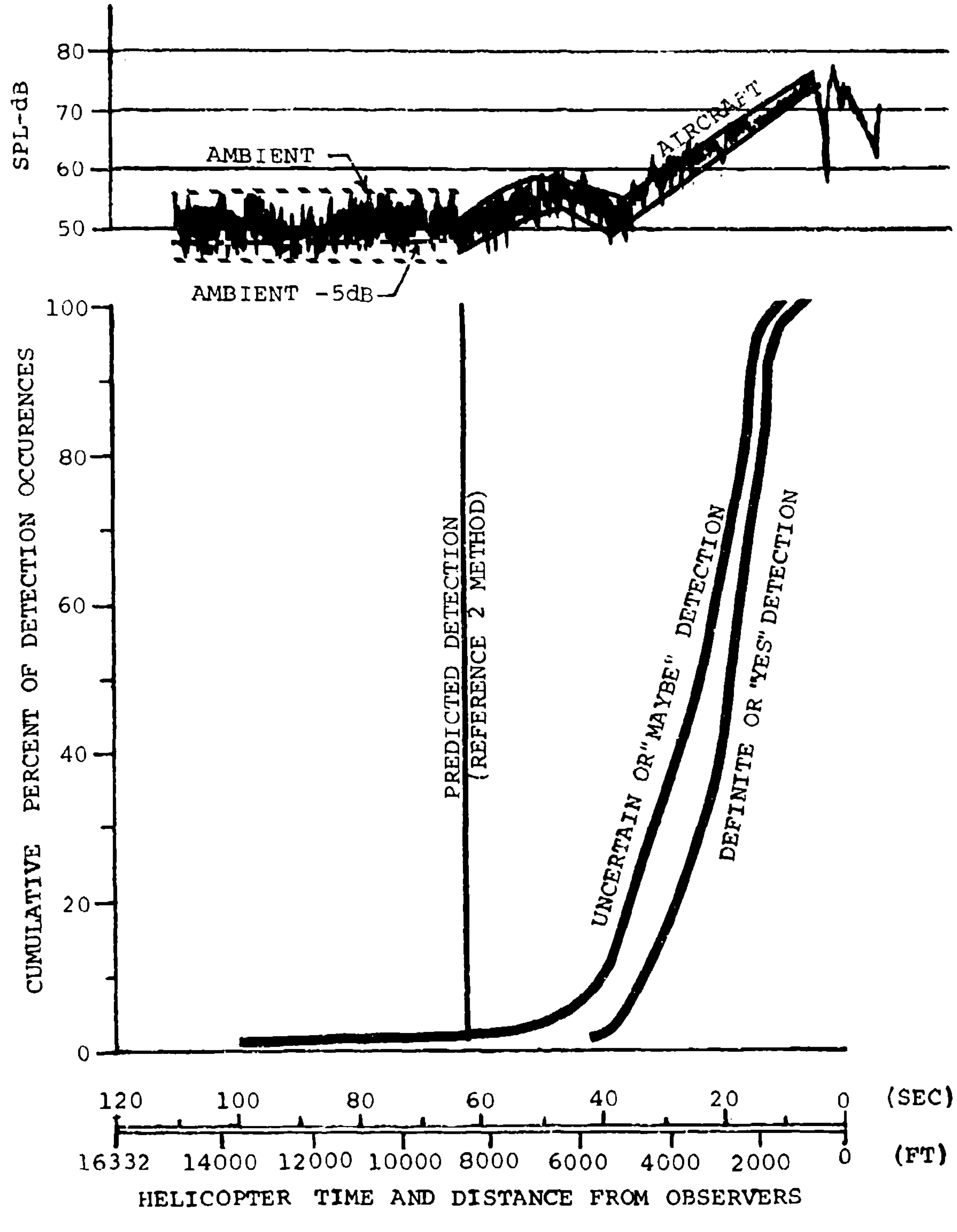


Figure 13. Relationship of Uncertain and Definite Detections.

Also shown in Figure 13 is the time history of the aircraft noise in the 31.5 Hz 1/3 octave band. This particular frequency band was displayed since 65% of the observers' detection occurred at the third harmonic of the main rotor blade passage frequency (32.4 Hz). The fundamental frequency (fo = 10.8 Hz) and its second harmonic fell below the audibility threshold and therefore did not influence detection. Appendix IV shows the helicopter noise time histories for each 1/3 octave band from 12.5 to 10,000 Hz. Since the microphone used to record the aircraft sound pressure level also recorded the natural ambient of the test site prior to the arrival of the helicopter, the noise spectrum shown illustrates the Reference 2 predicted detection distance for the natural ambient condition. When the SPL of the aircraft is 5 dB below the SPL of the ambient, the aircraft is approximately 8500 feet from the observers. At this distance, the test results show that only 1% of the uncertain detections and none of the definite detections had occurred.

Although the reasons for these differences cannot be rigorously separated by the results of this program, a few significant considerations may be:

1. A natural outdoor environment was used in place of a controlled laboratory atmosphere.

2. The sound pressure field of a helicopter is a completely different acoustical mechanism from that of a loudspeaker reproduction of the same sound.

3. In the laboratory there is no relative motion between the "aircraft" and the observer.

4. Simultaneous generation of extremely low and high frequencies is not a problem with the actual aircraft.

For the above reasons, it is considered likely that the results of this field test represent a less critical but more representative model of what can be expected of aural detection by personnel in actual situations.

3.3 EFFECTS OF AMBIENT NOISE SOURCES

The primary variable between test runs was the ambient noise in the vicinity of the observers. By varying the level, spectral shape, and temporal pattern of the ambient, the Reference 2 method of prediction was evaluated for several types of ambient. In addition to a flat and a 6 dB/octave sloped ambient, tape recordings of a military truck convoy and of modulated noise at the blade passage frequency of the main rotor were used to provide a more realistic acoustical background.

Figure 12 presented the total number of detection occurrences for all ambients. Figures 14, 15, and 16 separate the test results and show the distribution of detection occurrences for specific ambient spectrums.

3.3.1 EFFECTS OF FLAT AND SLOPED AMBIENTS

Figure 14 shows the distribution of the test results for the flat and 6 dB/octave sloped ambient spectrum. For the two spectrum shapes, the difference in the detection results is very small, approximately 2 dB. This small difference is probably due to limitations in the equipment output at the lower frequencies which resulted with the ambient noise not following a 6 dB/octave slope at the frequency range where the majority of detections occurred.

Specific test runs were conducted to change the detection frequency by removing octave bands from the ambient spectrum. In general, the detection frequency did not change for the majority of runs conducted. Also, the Δ SPL (aircraft-ambient) did not vary significantly.

Table III contains the results of the tests conducted with the flat ambient; Table IV, the sloped ambient. (It is significant to mention that the removal of the 500 Hz octave band from the sloped spectrum resulted in a change in the detection frequency from 31.5 Hz to 500 Hz.)

3.3.2 EFFECTS OF MODULATED NOISE

The results of using ambient noise with a temporal pattern are shown in Figure 15. When the modulated noise was used, (10.8 Hz frequency, 55 to 65 dB amplitude), the observers could not detect the helicopter until the difference between the aircraft and ambient SPL was approximately 2 dB above that required for unmodulated or steady ambients. This increase may be attributed to the observers confusion between the modulated ambient noise and the modulated helicopter noise, which required a larger difference between the two sounds before they were able to separate them.

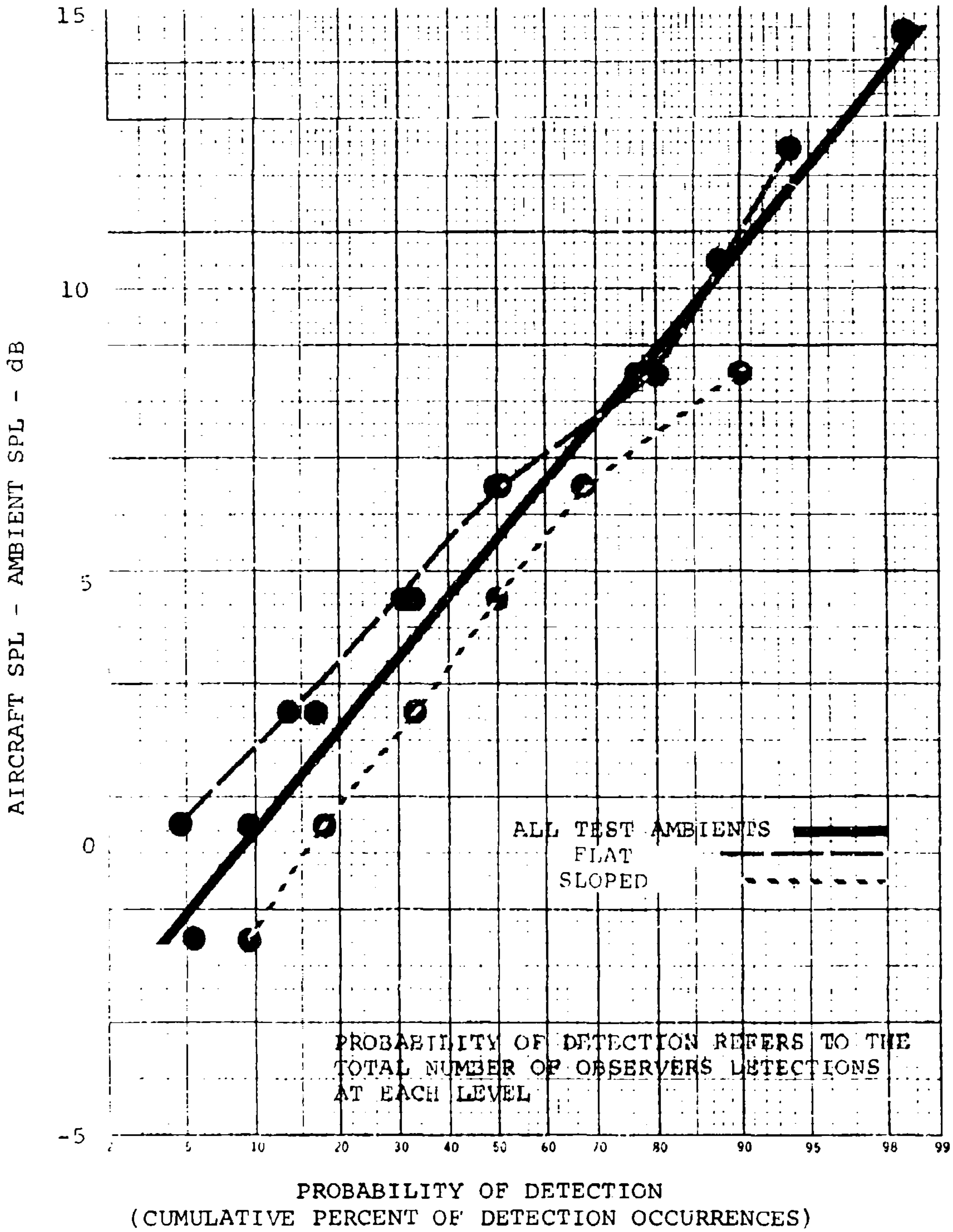


Figure 14. Detection Results With Flat and Sloped Ambient Noise Spectrums.

TABLE III. FLAT SPECTRUM OCTAVE BAND FREQUENCY DATA

Run No.	Ambient Octave Band Removed	Detection Freq. (Hz)	ΔSPL at Minimum Detection Dist. (A/C - Ambient) (dB)
6	None	31.5	9
7	31.5	40	12
8	63	31.5	12
9	125	31.5	9
10	250	31.5	10
11	500	31.5	11
12	1000	31.5	15
13	2000	31.5	7
14	4000	31.5	0

TABLE IV. SLOPED SPECTRUM OCTAVE BAND FREQUENCY DATA

Run No.	Ambient Octave Band Removed	Detection Freq. (Hz)	ΔSPL at Minimum Detection Dist. (A/C - Ambient) (dB)
18	None	31.5	3
25	None	31.5	9
19	31.5	31.5	13
20	63	31.5	9
21	125	500	5
22	250	31.5	6
23	500	500	12

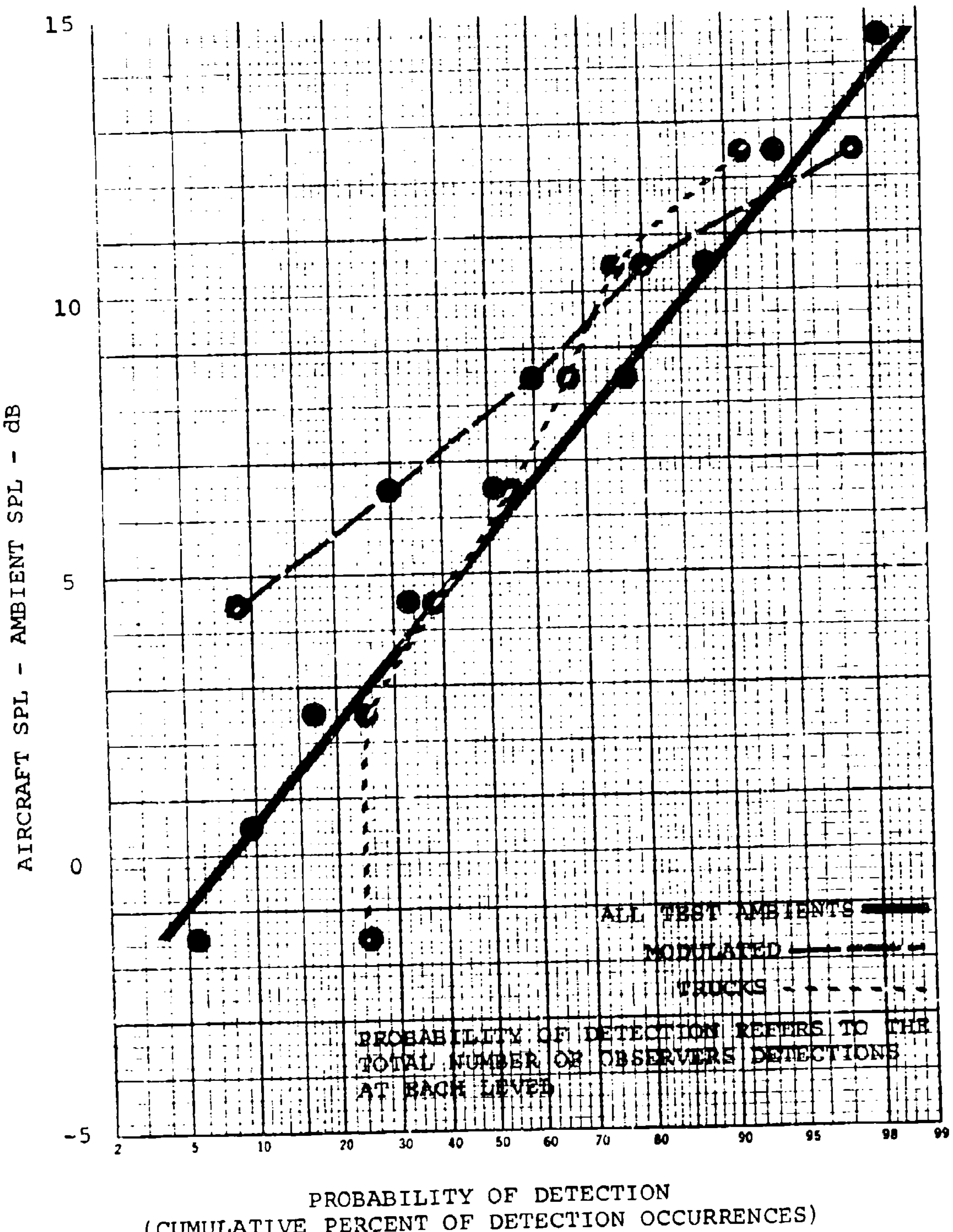


Figure 15. Detection Results With Modulated and Truck Ambient Noise Spectrums.

Also shown in this figure are the detection results with the truck noise ambient. Since the tape recording of the truck noise was comprised of several types of sounds, i.e., doors closing, engines idling and accelerating, and trucks leaving an area, the results shown cannot be compared to the other types of ambients tested.

3.3.3 EFFECTS OF AMBIENT NOISE LEVEL

The effects of ambient noise level on detection are shown in Figure 16 for the flat spectrum shape. Although testing with the low- and high-level flat ambient was limited to a few test runs, the trend shown in the results is considered to be significant. When the ambient noise was low (50-55 dB), the observers required a greater difference between the aircraft SPL and the ambient SPL than for the medium (55-65 dB) or high (65-75 dB) level ambient. This trend may be attributed to the differences in detection distances. When the ambient noise was high, the observers were detecting the aircraft at smaller distances than with the low-level ambient. Due to spherical spreading, the rate of change in the noise increased as the helicopter approached the observers. (As the helicopter distance changed from 4,000 to 1,000 feet, the rate of change in noise doubled). This change, being more noticeable to the observer as distance between the aircraft and observer decreased, resulted in a 3 dB reduction in the $\triangle$ SPL (aircraft-ambient) for the high-level ambient.

3.3.4 DETECTION FREQUENCY

As mentioned in Section 3.2, the majority of detections occurred at the third harmonic of the main rotor blade passage frequency (32.4 Hz). Shown in Figure 17 is the summary of precentage of detections at each 1/3 octave. At the fundamental tail rotor blade passage frequency, $f_o = 85$ Hz, the test results show that only 2% of the detections occurred. However, during the test, several observers commented that they thought that they were detecting the helicopter by the noise generated by its tail rotor rather than the lower frequency main rotor noise. The reason(s) for this apparent disagreement between the calculated results and the observers' qualitative assessment is not understood at this time.

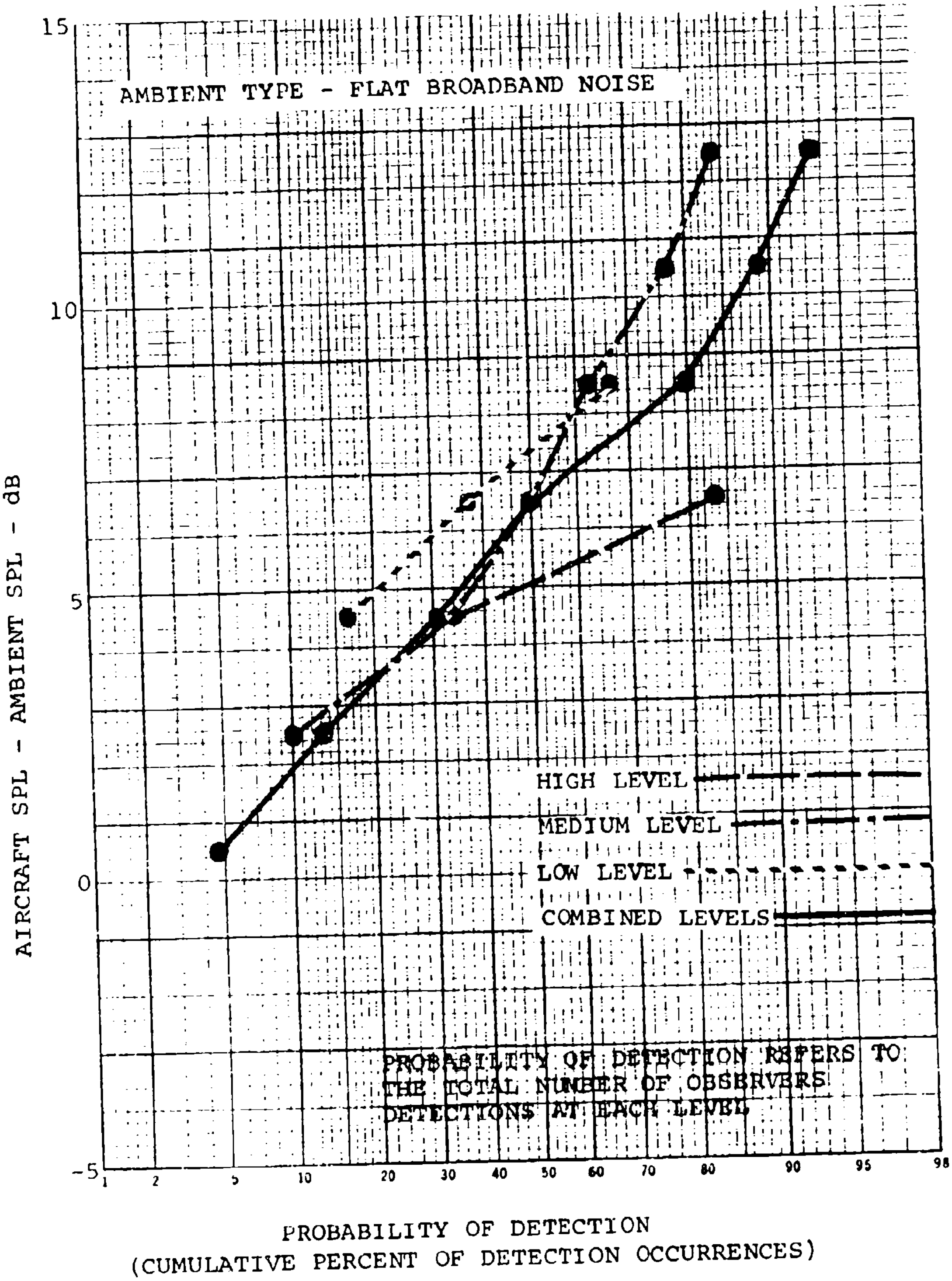


Figure 16. Effects of Ambient Noise Level on Detection.

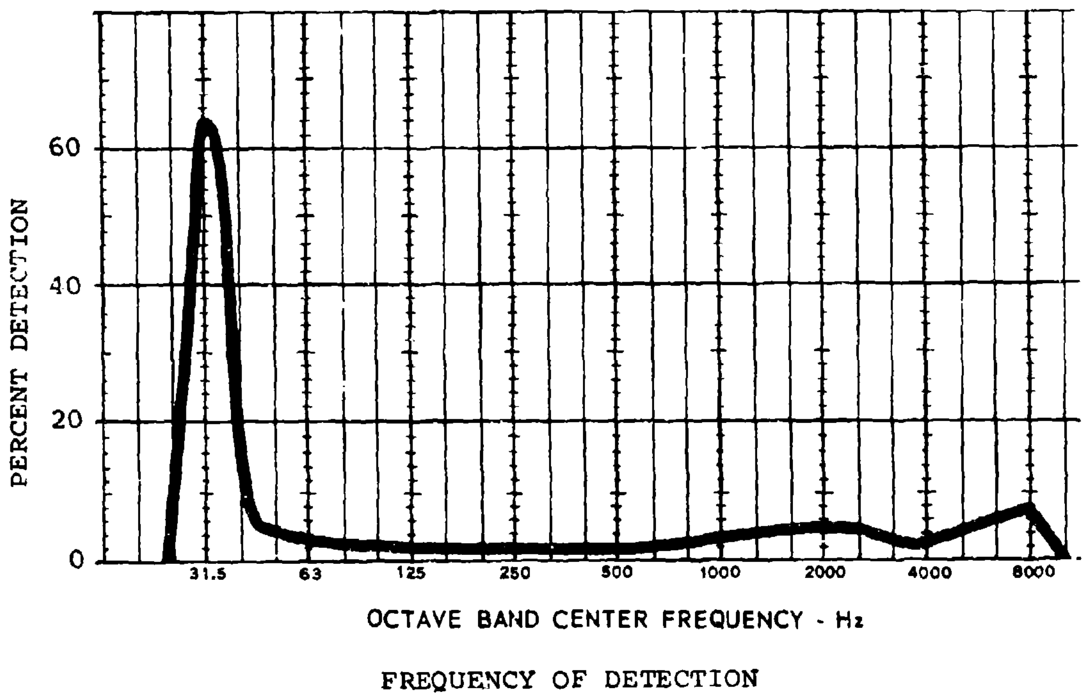


Figure 17. Summary of Detection Frequencies.

4.0 CONCLUSIONS

A test program was conducted which measured detection data on a light commercial helicopter. By comparing the actual field detection measurements with analytically predicted results, the Reference 2 method of helicopter aural detection was evaluated. The major conclusions drawn from this evaluation are summarized below.

1. The Reference 2, Appendix IV, method of predicting detection, i.e., the distance when the aircraft sound pressure level in any frequency band is 5 dB below the ambient sound pressure level, is extremely conservative for detection at the low frequency bands. The test results showed that aural detection generally (i.e., 50% probability of group detection) does not occur until the aircraft SPL is 5 dB above the ambient SPL.

2. Use of the Reference 2, Appendix IV, method could result in predicting detection at distances in excess of twice the actual measured detection distance.

3. Although the majority of detections occurred at the lower frequencies of the main rotor, it is the authors experience that helicopter detection does in fact occur at these lower frequencies due to atmospheric attenuation of the higher frequencies.

4. Parameters which appear to influence the detection distance other than the relationship of the aircraft SPL and the ambient SPL may be:

   a. The rate of change of noise which, due to spherical spreading, increases as the distance between the helicopter and observers decreases. At smaller distances, the increased rate of change in the aircraft noise results in the observer's being able to separate the aircraft noise from the ambient noise at lower differences between the two signals.

   b. The absolute sound pressure level of the aircraft and ambient in addition to the relative levels of the two signals.

Since the results of this test program were derived from the use of only one type of helicopter, it is recommended that further testing be conducted using other types of helicopter sounds. It is also recommended that further efforts be made to determine the effects of other parameters on detection such as those mentioned above.

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1. CH-47 HELICOPTER MAN-MACHINE-ENVIRONMENT COMPATIBILITY EXPERIMENT, U. S. Army Combat Developments Command Experimentation Command, Fort Ord, California, September 1968.

2. Ollerhead, J. B., HELICOPTER AURAL DETECTABILITY, Wyle Laboratories; USAAMRDL Technical Report 71-33, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, July 1971, AD 730788.

3. Stuverude, H. N., The Boeing Co. 1972 INDEPENDENT RESEARCH AND DEVELOPMENT PROGRAM, Boeing Vertol Company D210-10379-1, The Boeing Vertol Company, Philadelphia, Pennsylvania, March 1972.

APPENDIX I
INSTRUCTIONS TO TEST OBSERVERS

1. You are here to participate in an experiment on the aural detection of helicopters. The purpose of this experiment is to evaluate existing analytical prediction methods of detection.

2. You will be detecting the aircraft under various ambient conditions which will be heard over the two loudspeakers located on the opposite side of this screen. This screen is here to visually screen you from the helicopter. Please do not change the position of your seat during the test.

3. Each of you has been given an electrical switch box. There are three positions on each box. The center position is the off position. The position marked "MAYBE" will be used when you think you hear a helicopter but are not certain. You may select this position more than once. However, once you are certain that you hear a helicopter, select the "YES" position. This position can be selected only once for each run, so you should be absolutely sure that you hear a helicopter when you select "YES". To stress this important item, you should be sure that you hear a helicopter to the extent that in an actual situation you would notify others of the helicopters approach. When you select "MAYBE" and "YES" you do not have to hold the switch in the selected position; just select the position and release the switch.

4. The microphone in front of you is an open microphone. Anything you say or any sound you make during a run will be recorded on the data tape. So it is important to remain completely silent and still during the run. If there is any need to communicate with the Lab you may use this microphone, however, wait until a run is complete. You may relax and talk in between the runs.

5. You will be notified over the loudspeakers when a run is to start. The instruction will be ... mark --- start of run # ___. When you hear this instruction, you are to stop all talk and remain still until the end of the run. During the run you will be detecting the aircraft and selecting the switches. Again, you will be notified at the end of each run by the instruction ... mark --- end of run # ____. During the initial runs, you will become familiar with the helicopter noise that you will be detecting.

6. If there are any comments that you would like to make about a particular run for example, you heard a jet aircraft fly overhead during the run or you were disturbed by an insect or any situation that may have occurred, please write them on the cards provided.

7. Please base your decision according to when you detect the helicopter --- there are no right or wrong answers, and it is important that you do not watch the person next to you during a run and allow him to influence your decision.

APPENDIX II
OBSERVATION AND ACOUSTICAL DATA

This appendix contains the detection observation and acoustical data for each test run conducted. Two graphs are shown for each test run with the exception of runs 28, 39 and 40, which are not presented due to data unavailability (These runs were repeated ambient conditions of runs 4, 5 and 30.) The upper graph on each page shows the detection distances at which each observer definitely detected the helicopter. The graphs shown on the lower half of each page show the sound pressure levels of the controlled ambient noise at the observers' location and also the mean aircraft noise signature plus the ambient noise at the remote microphone location for the minimum and maximum detection distances. The absolute threshold of audibility from Table IX of Reference 2 Appendix IV is also displayed.

Each graph has an ambient condition code listed at the top, and Table V identifies the symbols used.

TABLE V. AMBIENT CODE IDENTIFICATION

Type		Level	Octave Bands Removed-Hz
F	- Flat	L-Low(50-55 dB)	1 - 31.5
M_L	- Modulated, Low Rate	M-Medium(55-65 dB)	2 - 63
M_M	- Modulated, Medium Rate	H-High(65-75 dB)	3 - 125
M_H	- Modulated, High Rate		4 - 250
N	- Natural		5 - 500
S_L	- Sloped		6 - 1000
St	- Steady		7 - 2000
T	- Truck		8 - 4000

EXAMPLE: S_L-M-3

Sloped broadband noise, medium level, with the 3d octave (125 Hz) removed.

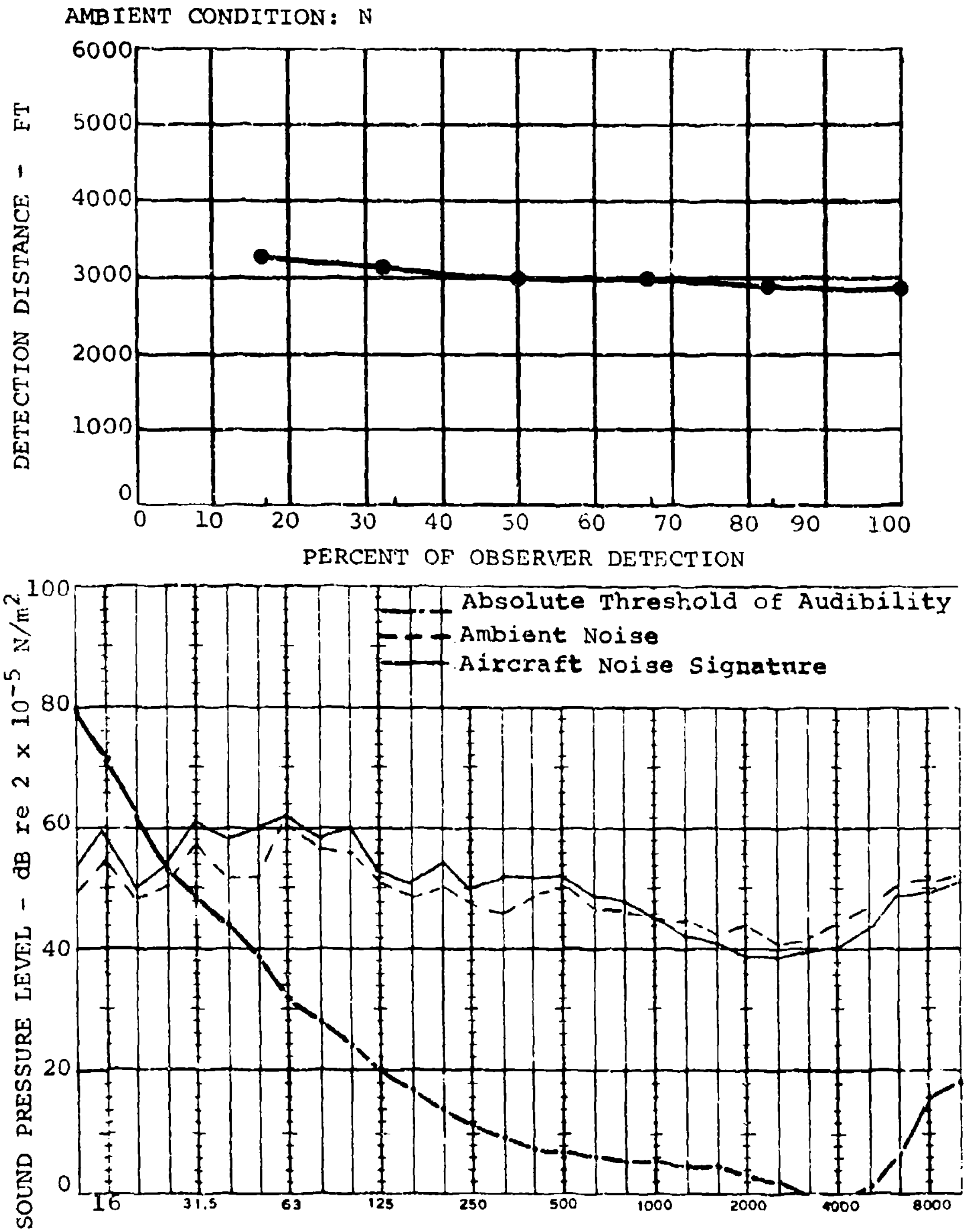


Figure 18. Observation and Acoustical Data - Run 1.

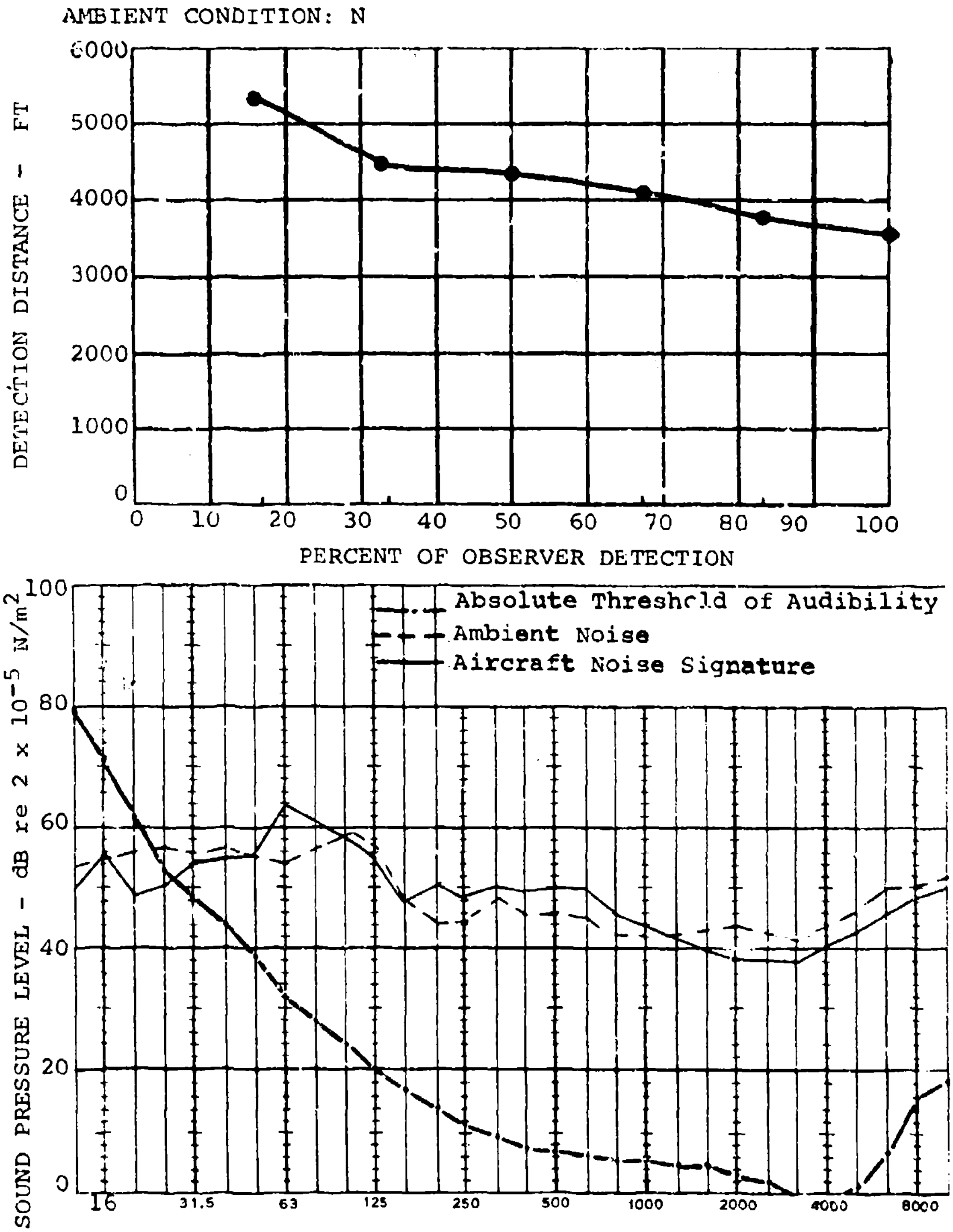


Figure 19. Observation and Acoustical Data - Run 2.

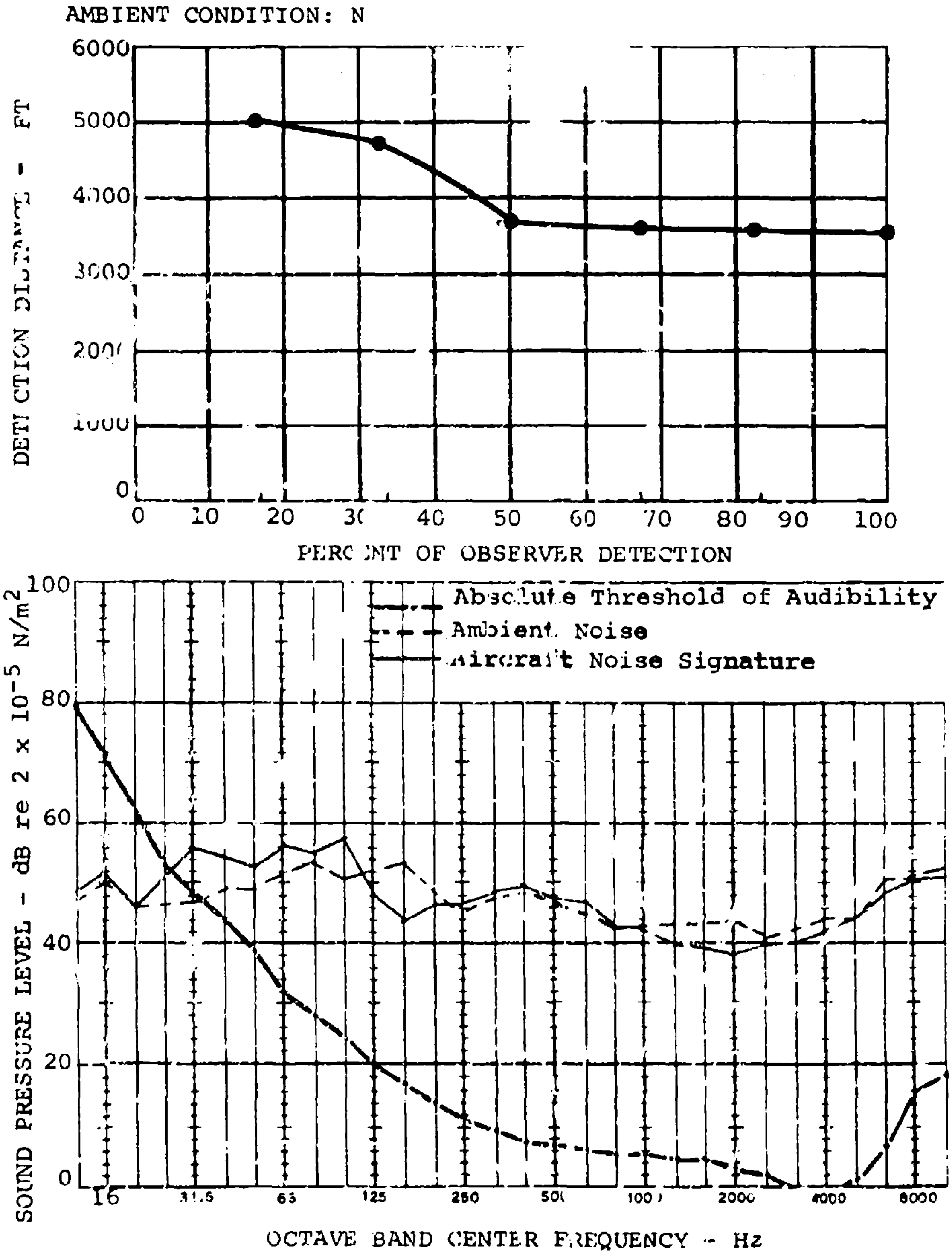


Figure 20. Observation and Acoustical Data - Run 3.

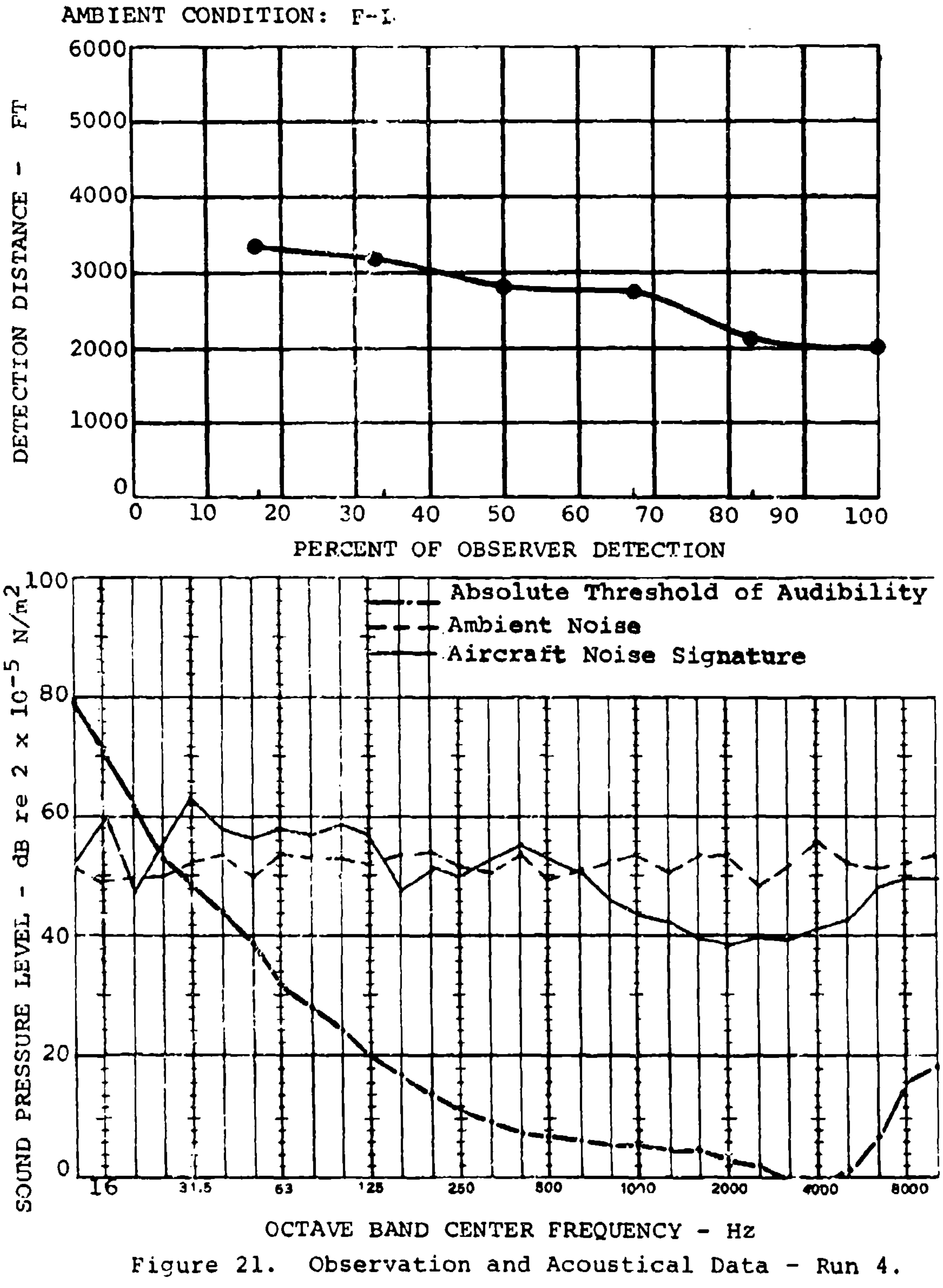


Figure 21. Observation and Acoustical Data - Run 4.

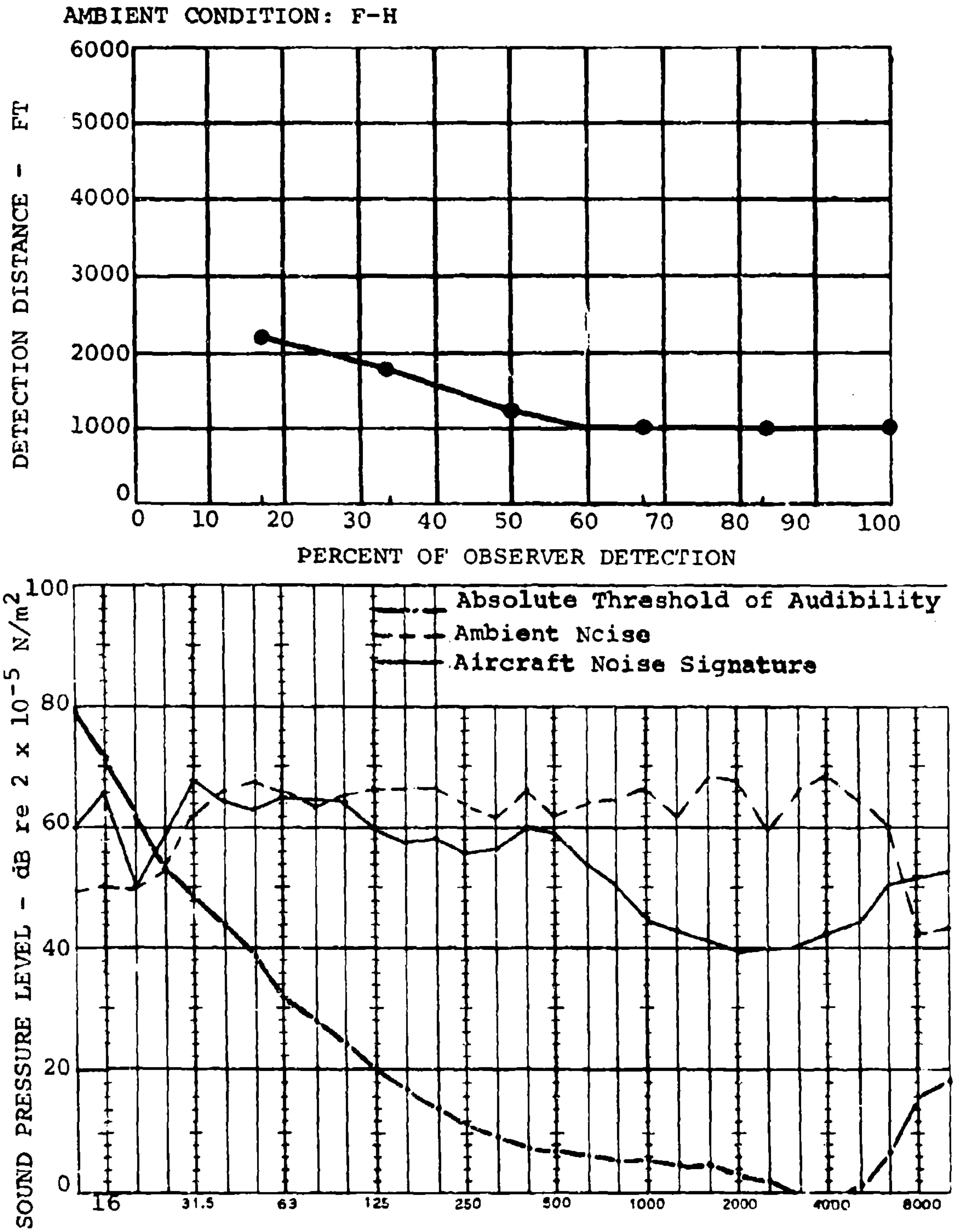


Figure 22. Observation and Acoustical Data - Run 5.

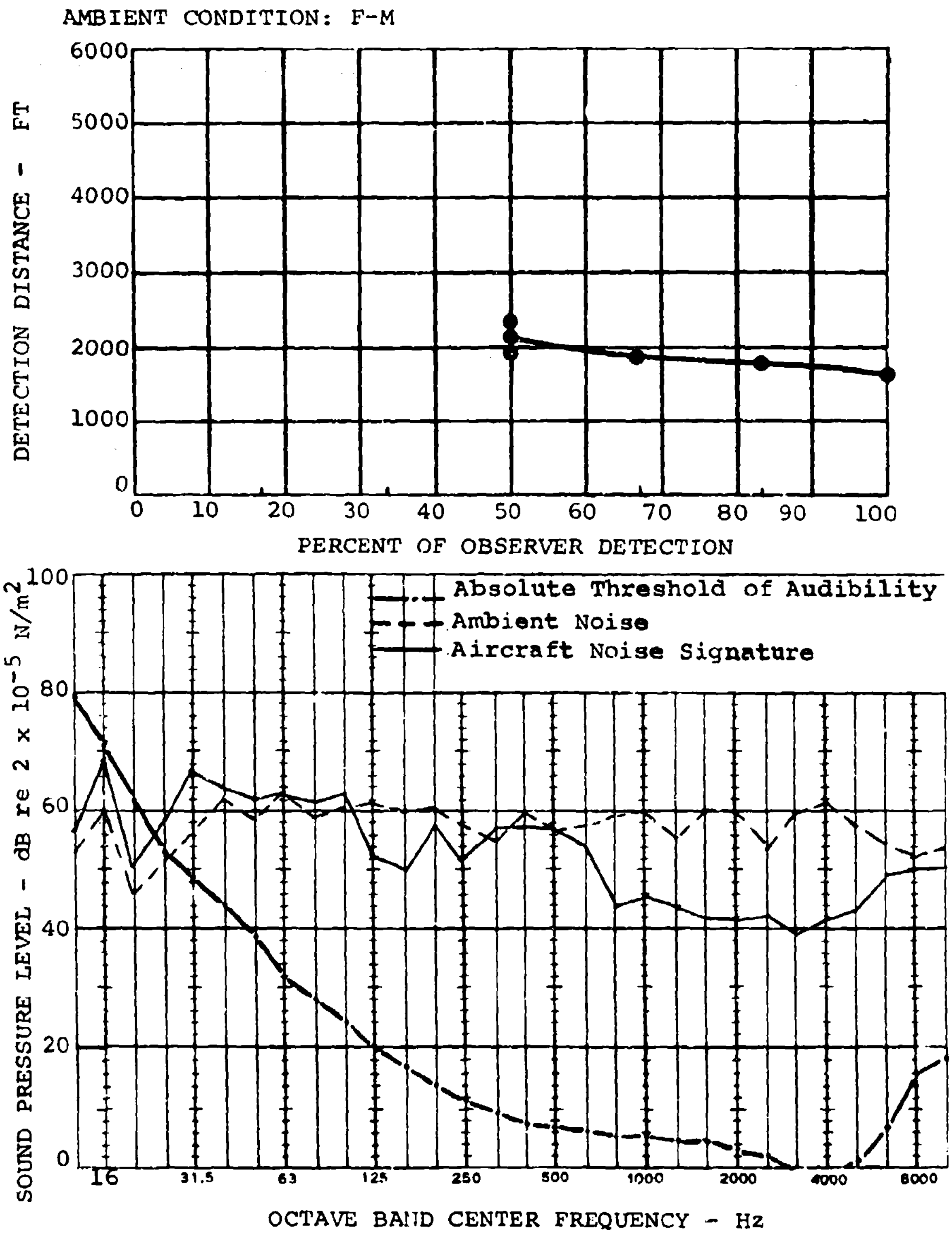


Figure 23. Observation and Acoustical Data - Run 6.

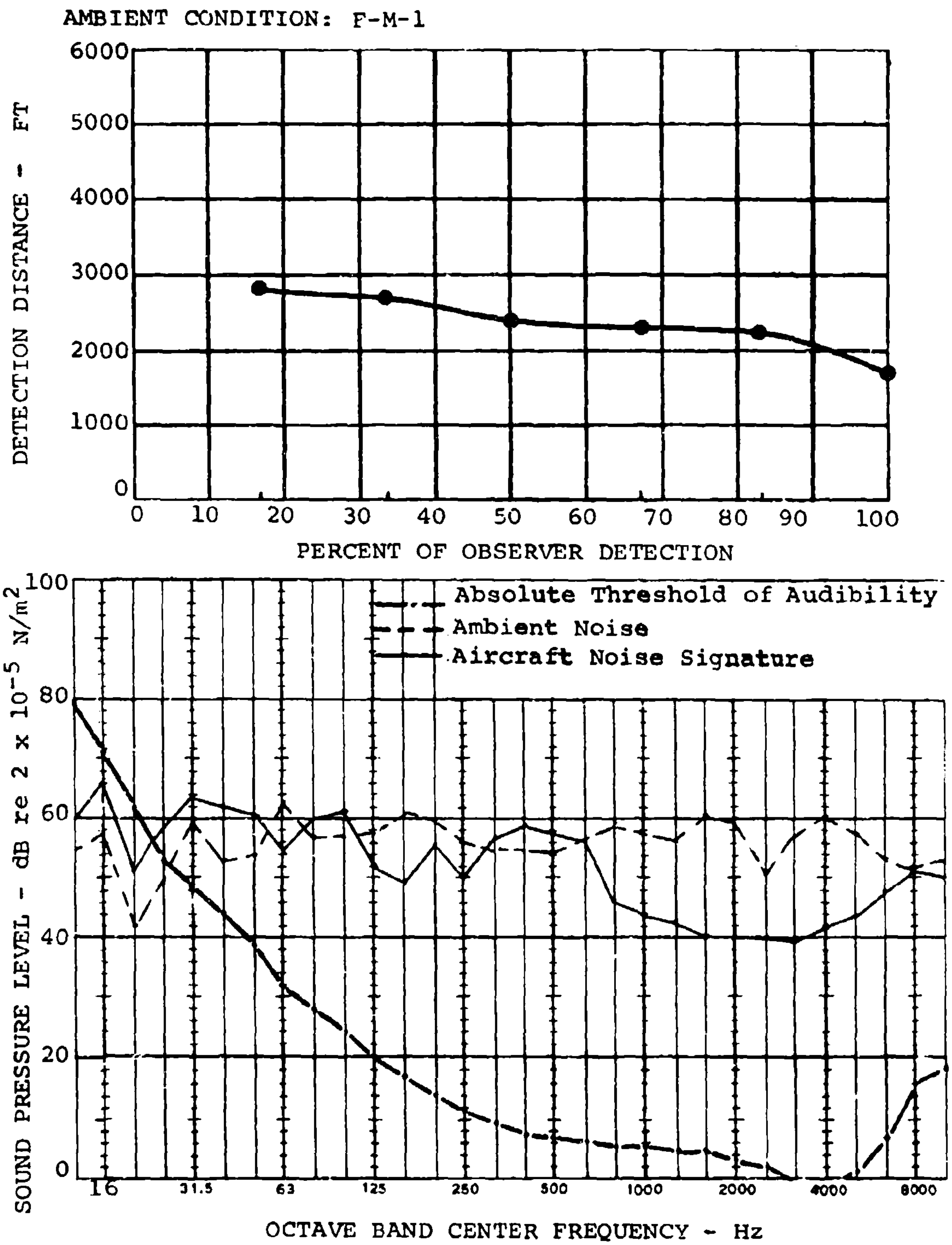


Figure 24. Observation and Acoustical Data - Run 7.

AMBIENT CONDITION: F-M-2

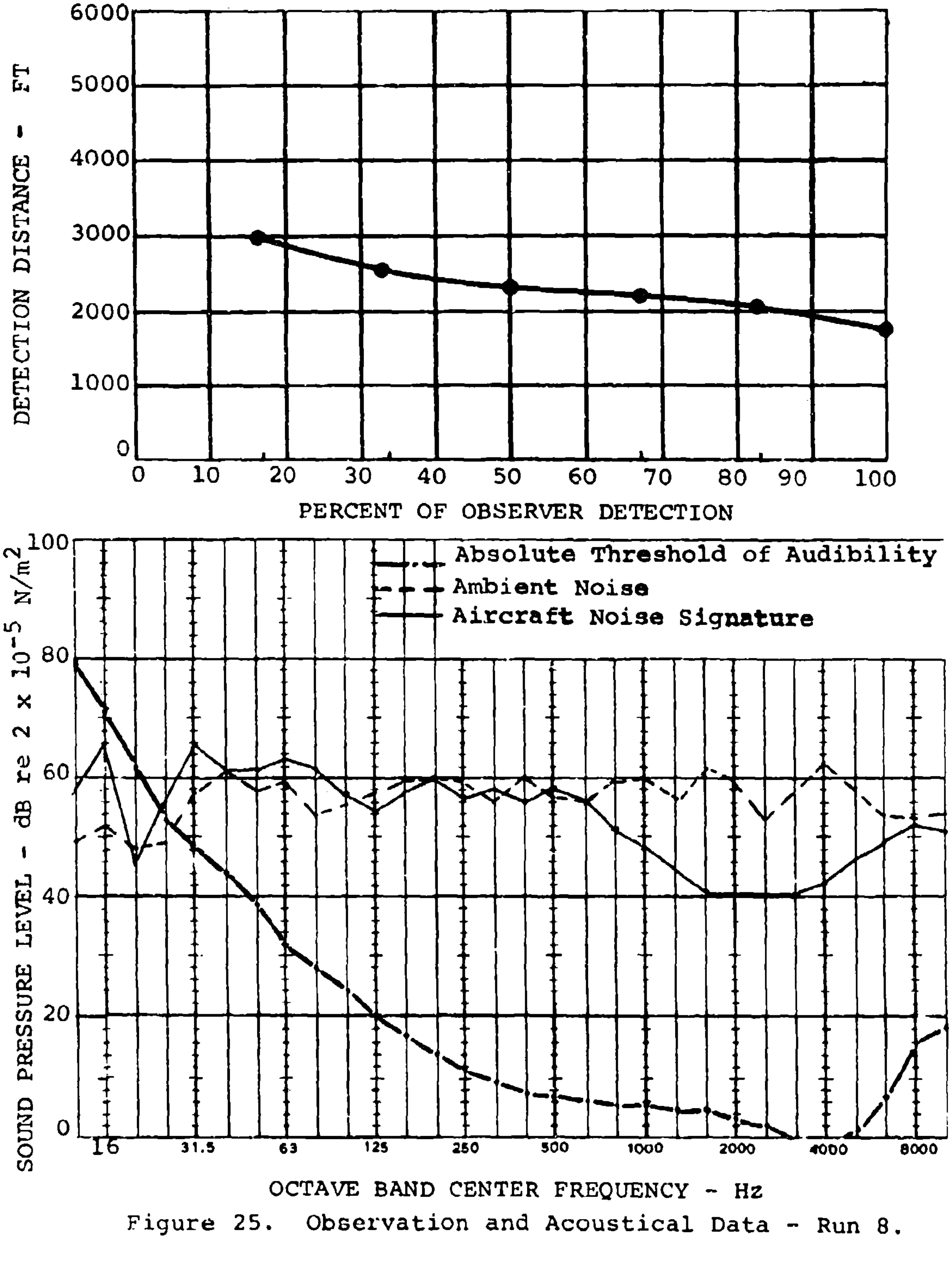


Figure 25. Observation and Acoustical Data - Run 8.

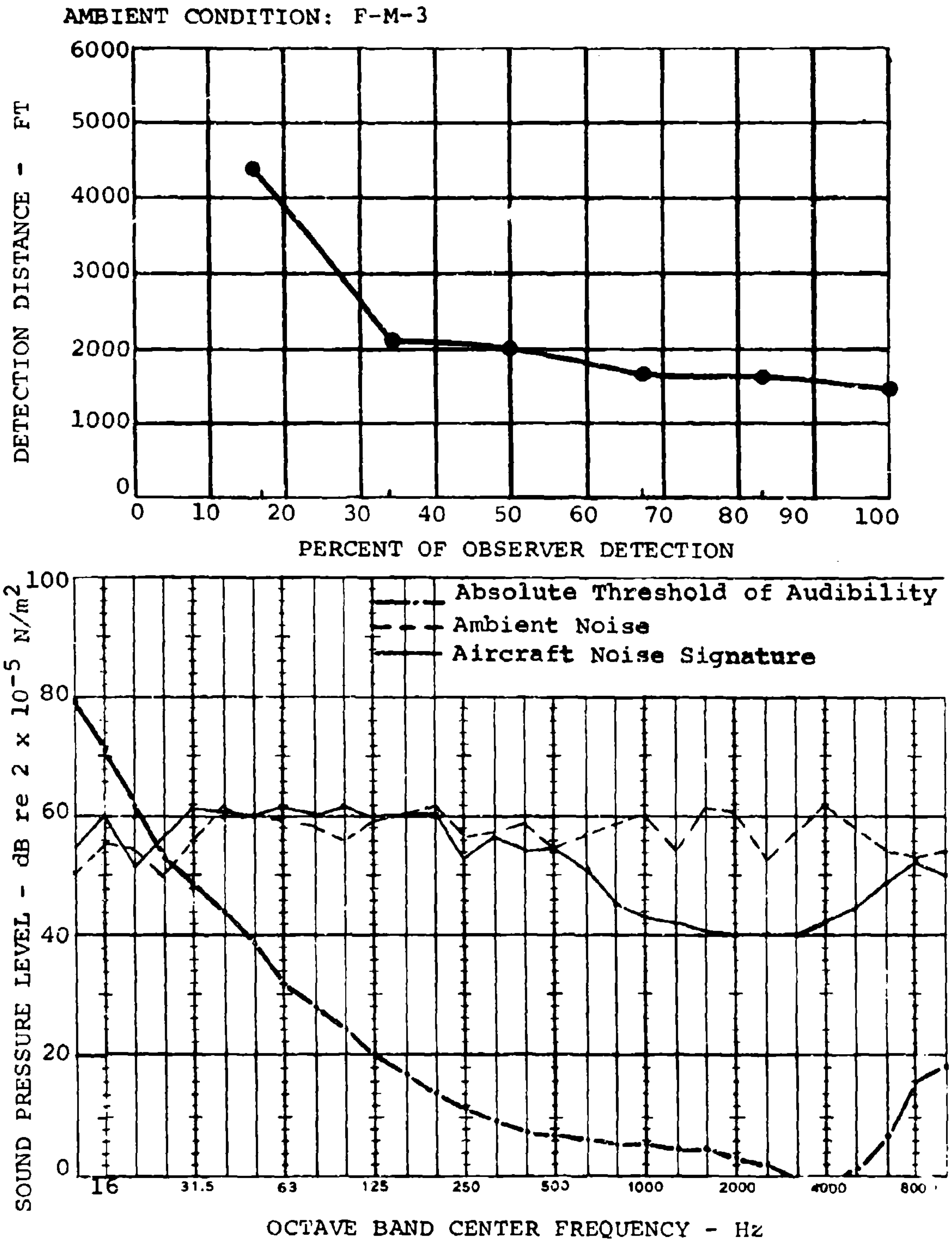


Figure 26. Observation and Acoustical Data - Run 9.

AMBIENT CONDITION: F-M-4

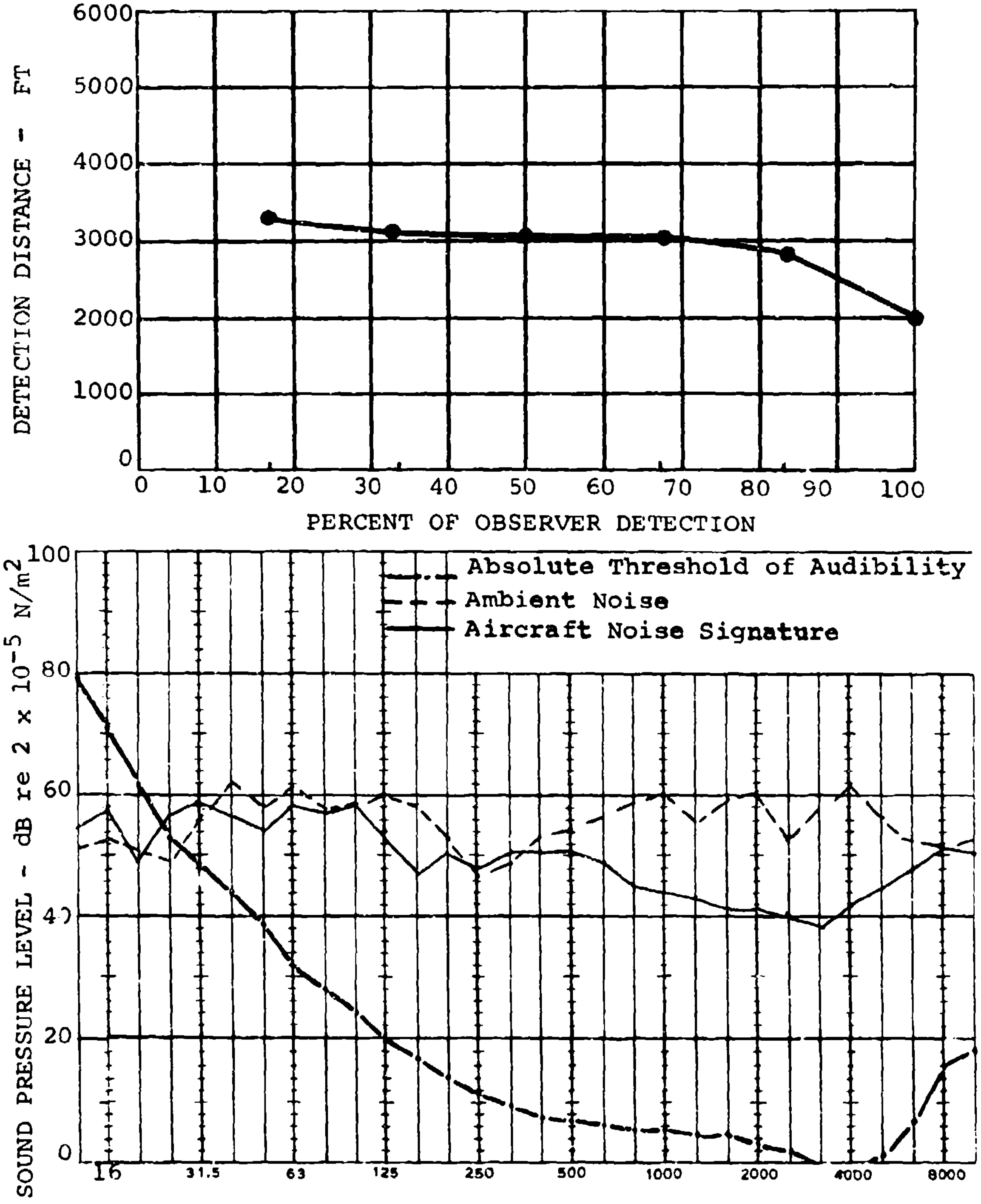
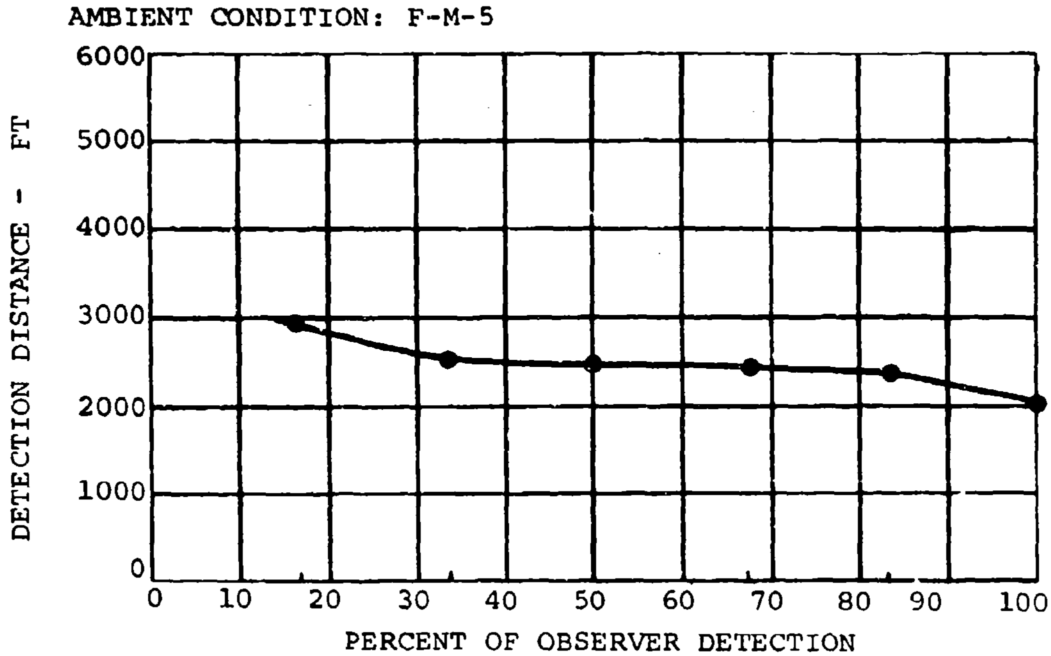


Figure 27. Observation and Acoustical Data - Run 10.



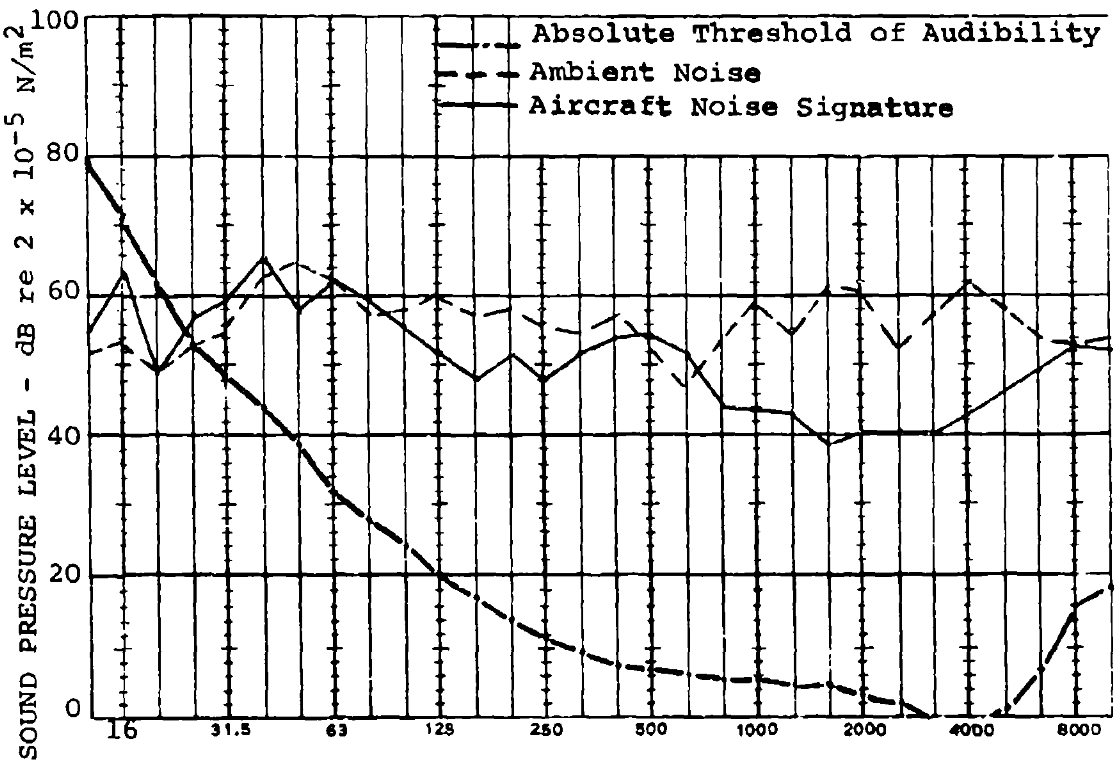


Figure 28. Observation and Acoustical Data - Run 11.

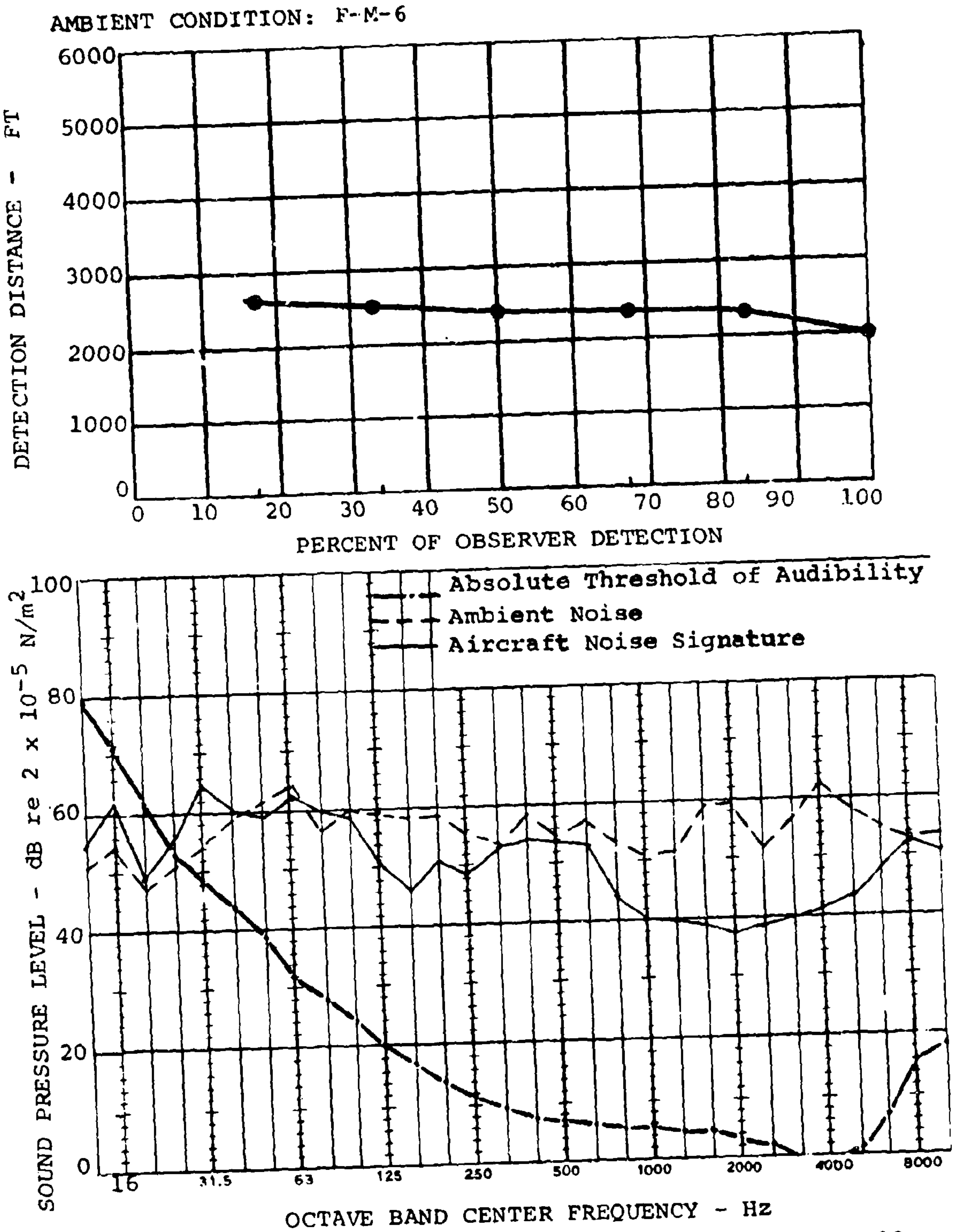


Figure 29. Observation and Acoustical Data - Run 12.

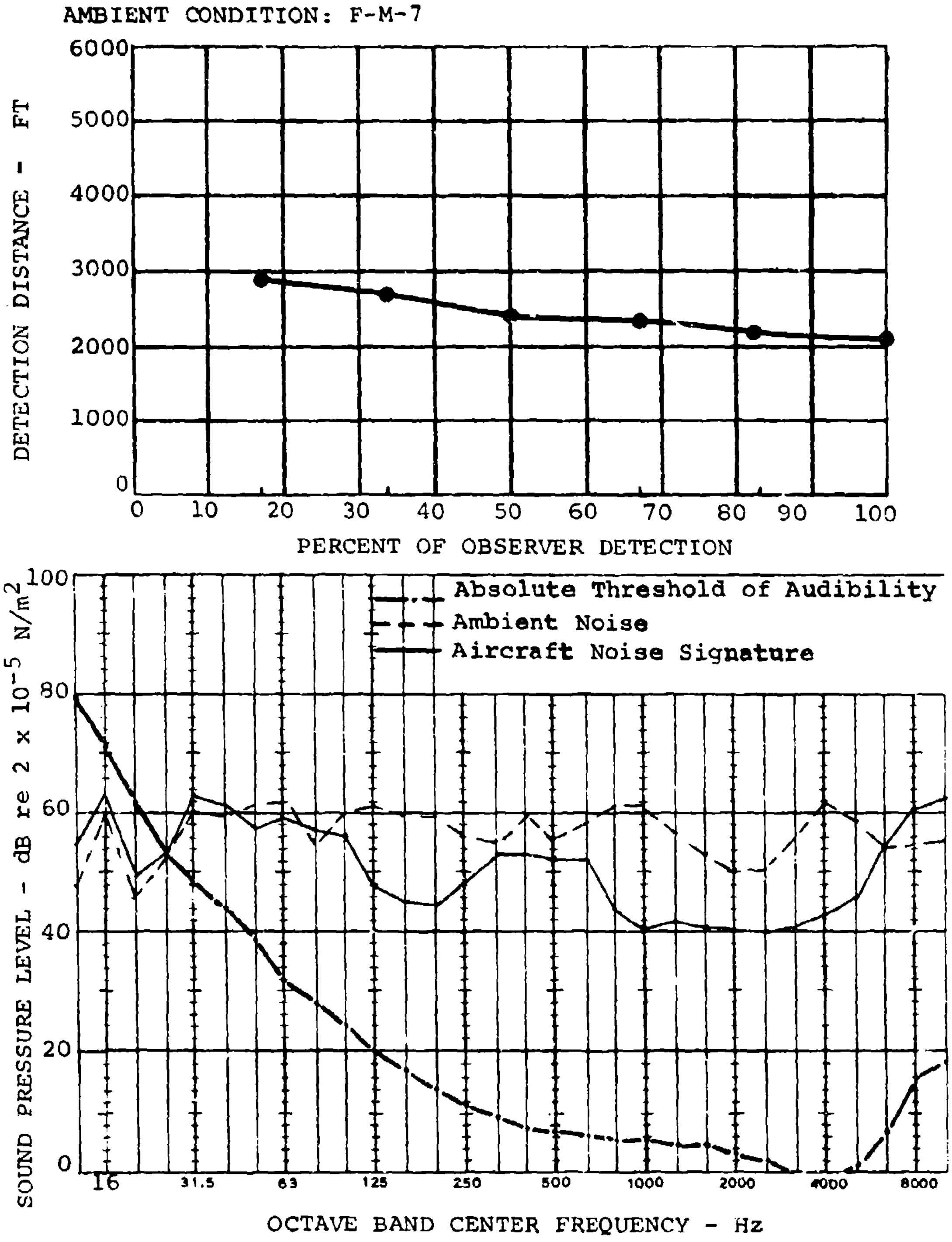


Figure 30. Observation and Acoustical Data - Run 13.

AMBIENT CONDITION: F-M-8

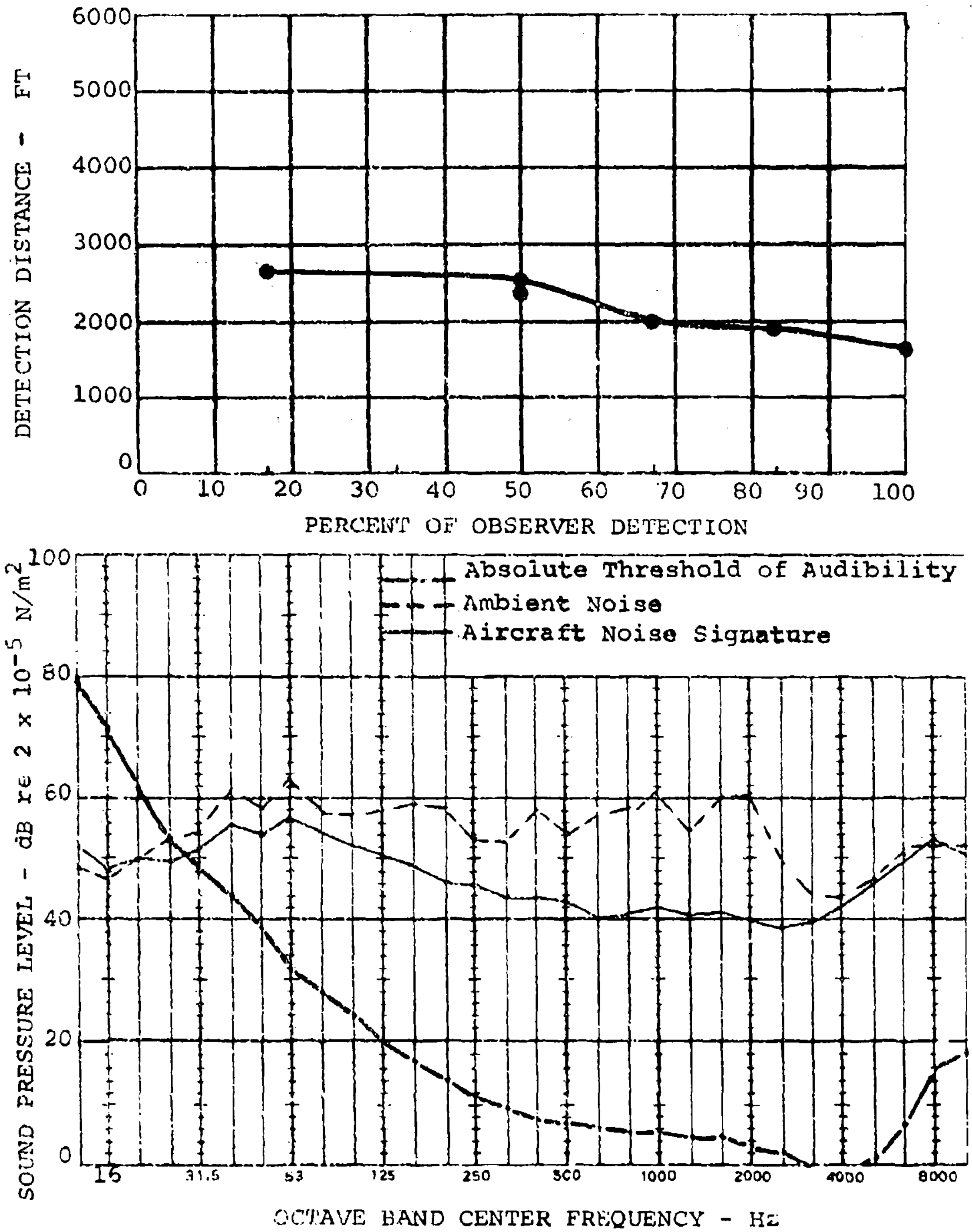


Figure 31. Observation and Acoustical Data - Run 14.

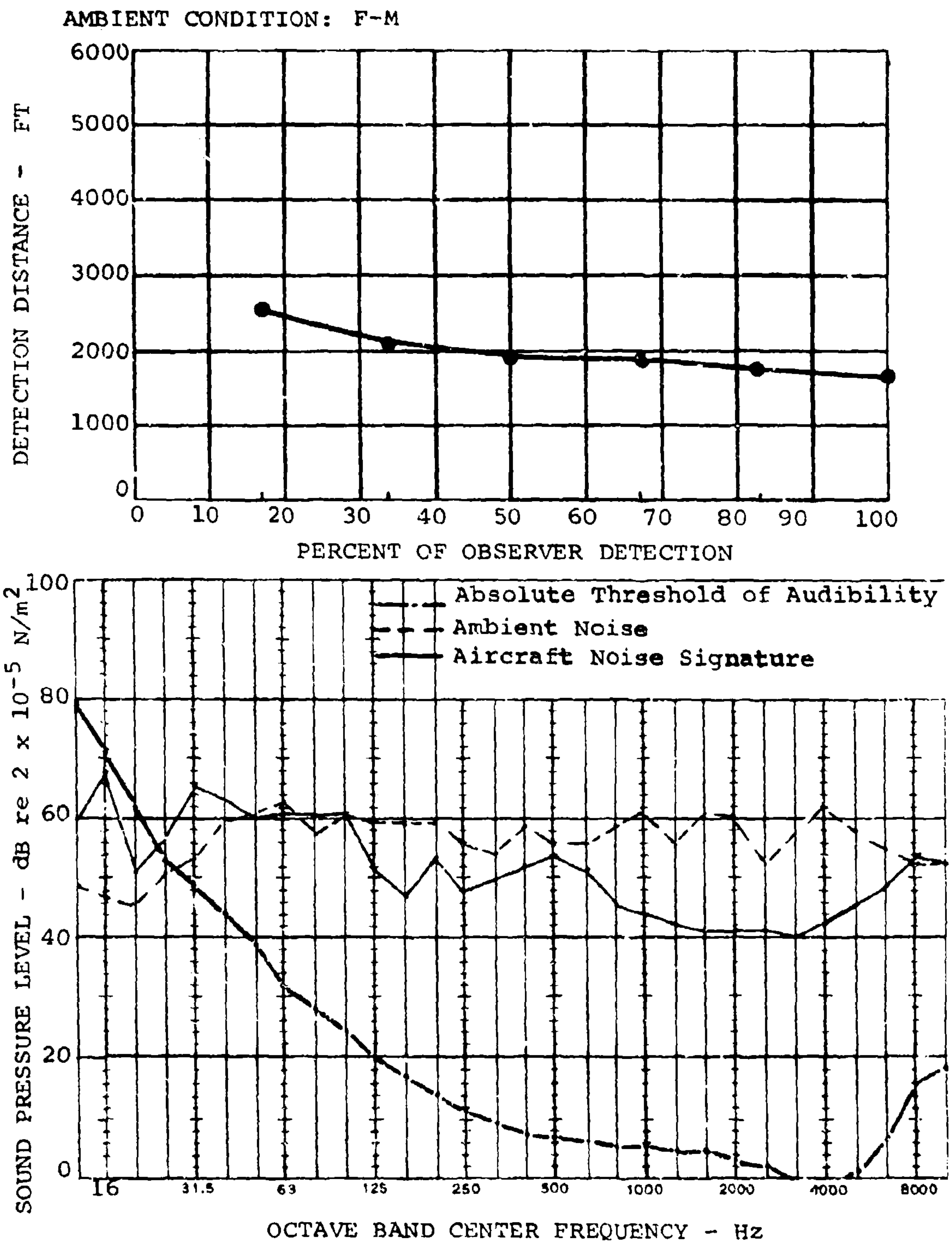


Figure 32. Observation and Acoustical Data - Run 15.

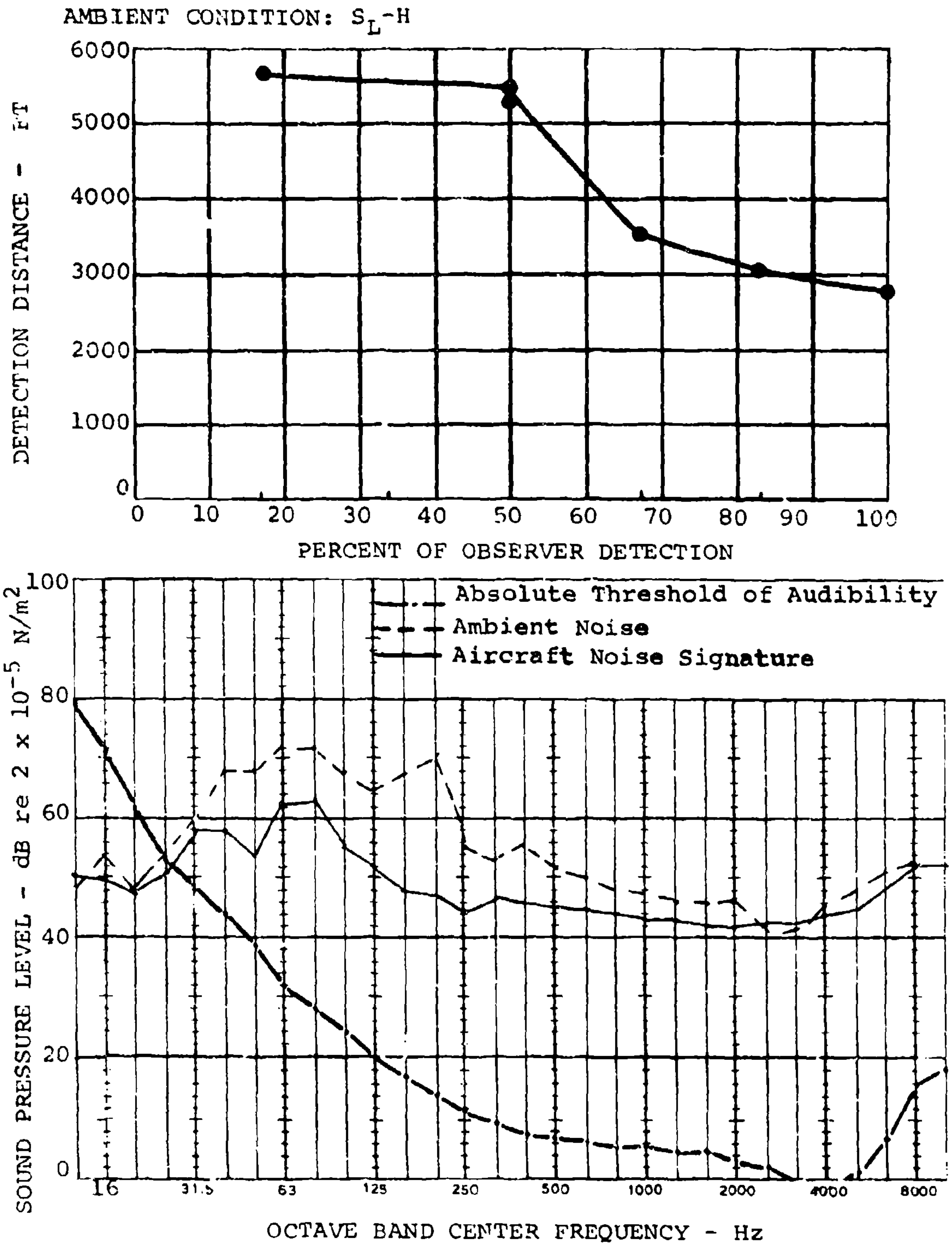


Figure 33. Observation and Acoustical Data - Run 16.

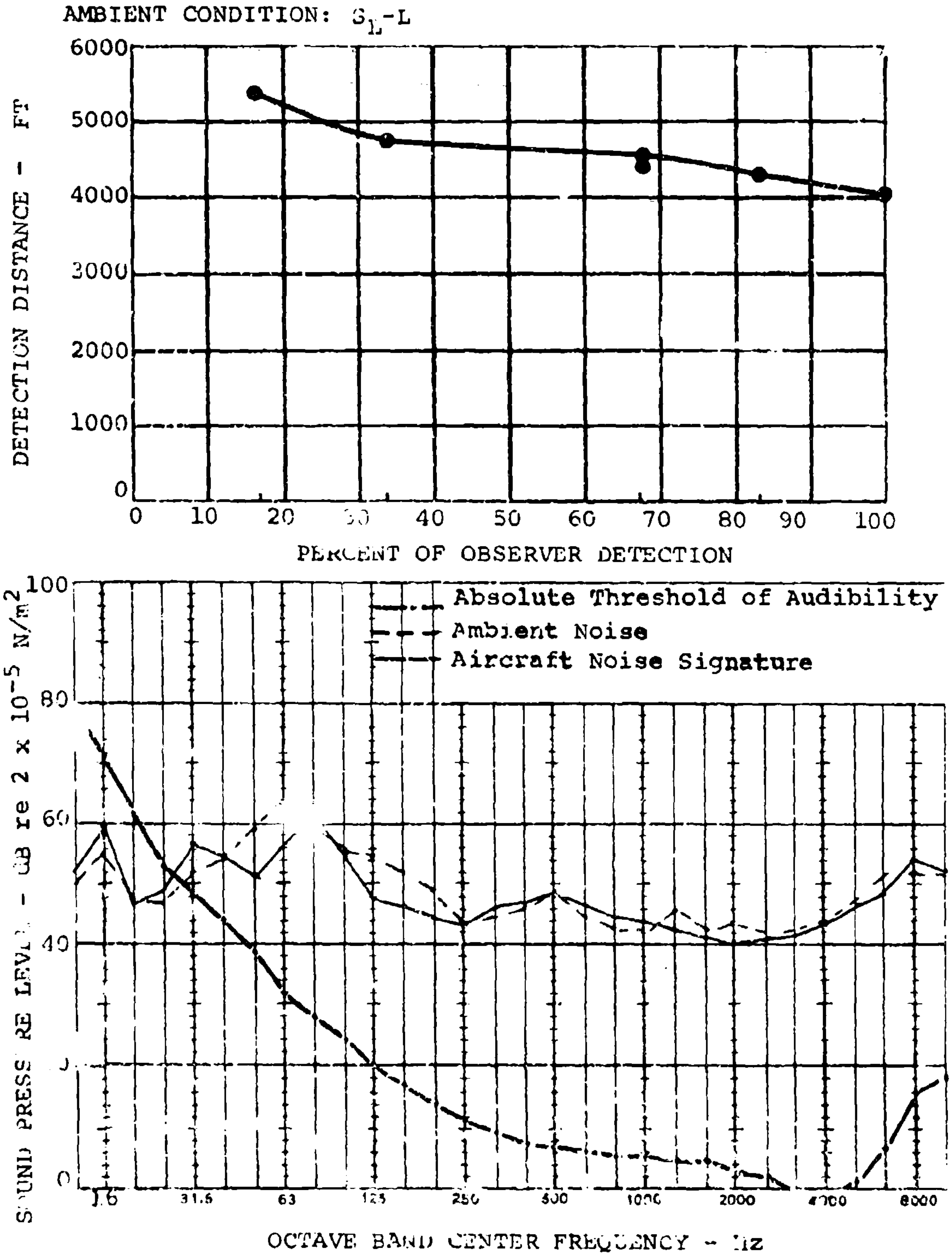


Figure 34. Observation and Acoustical Data - Run 17.

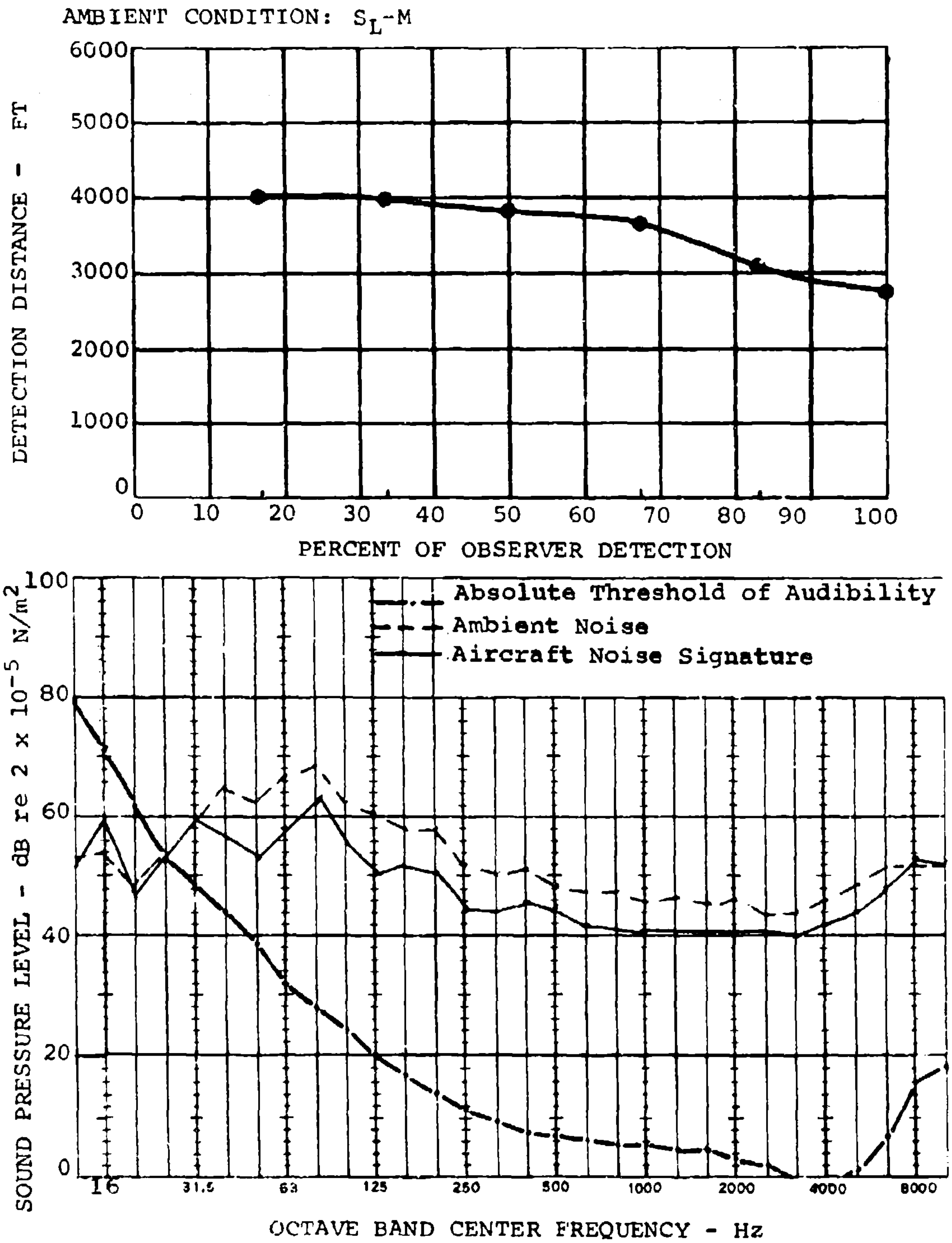
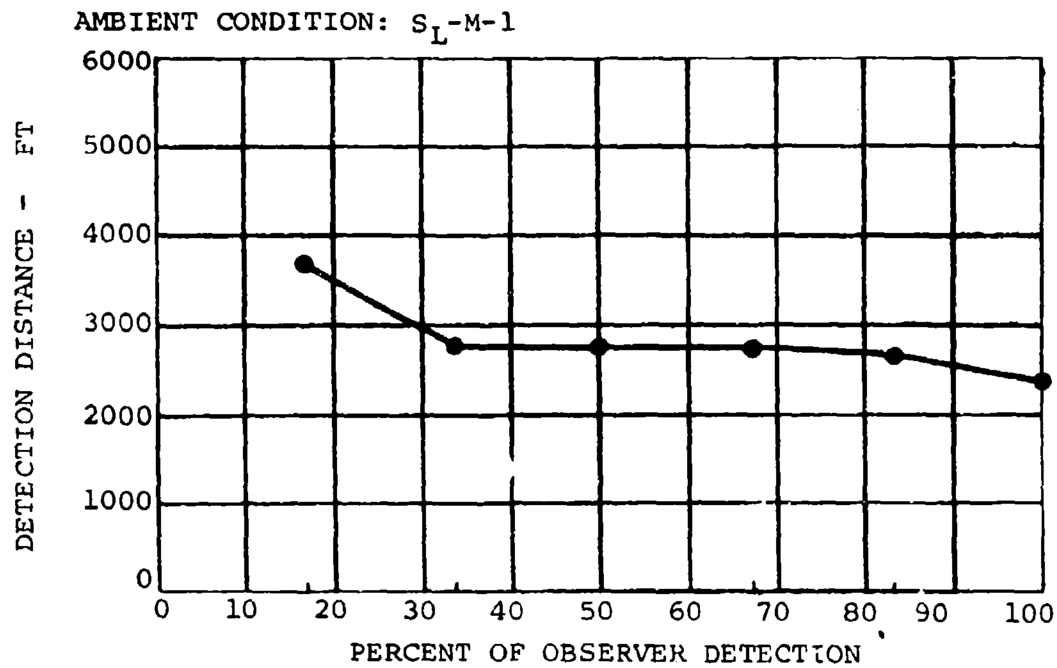


Figure 35. Observation and Acoustical Data - Run 18.



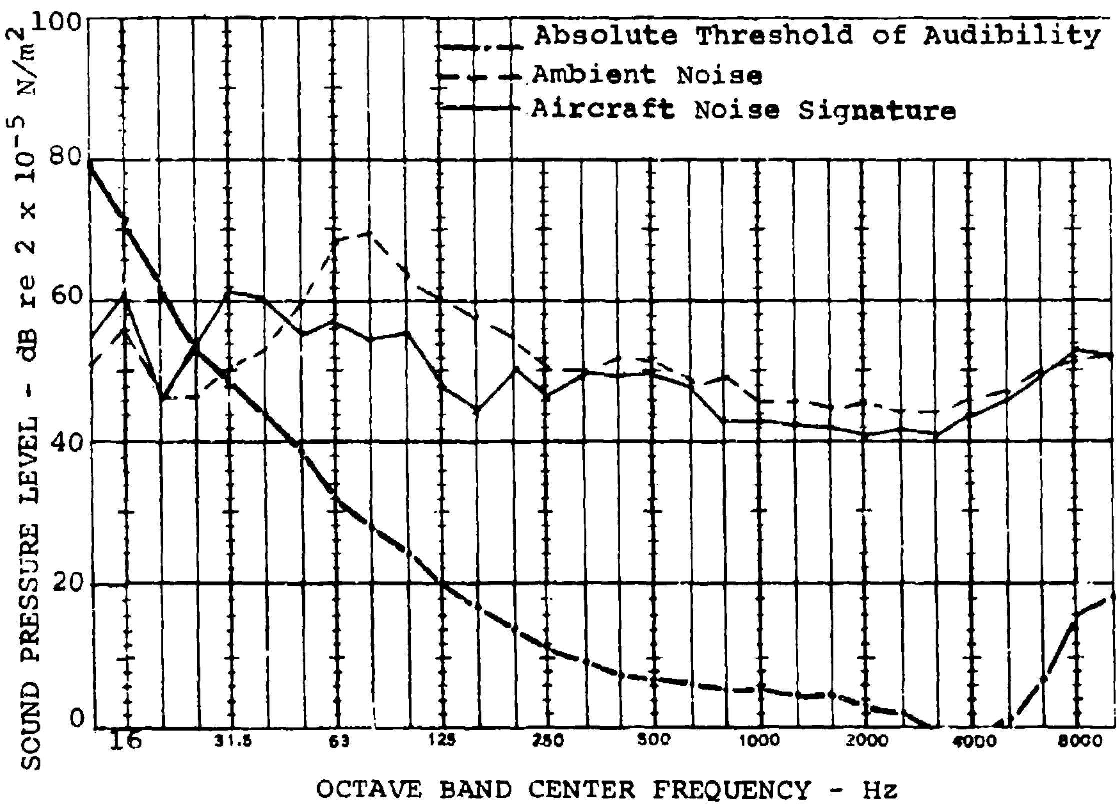


Figure 36. Observation and Acoustical Data - Run 19.

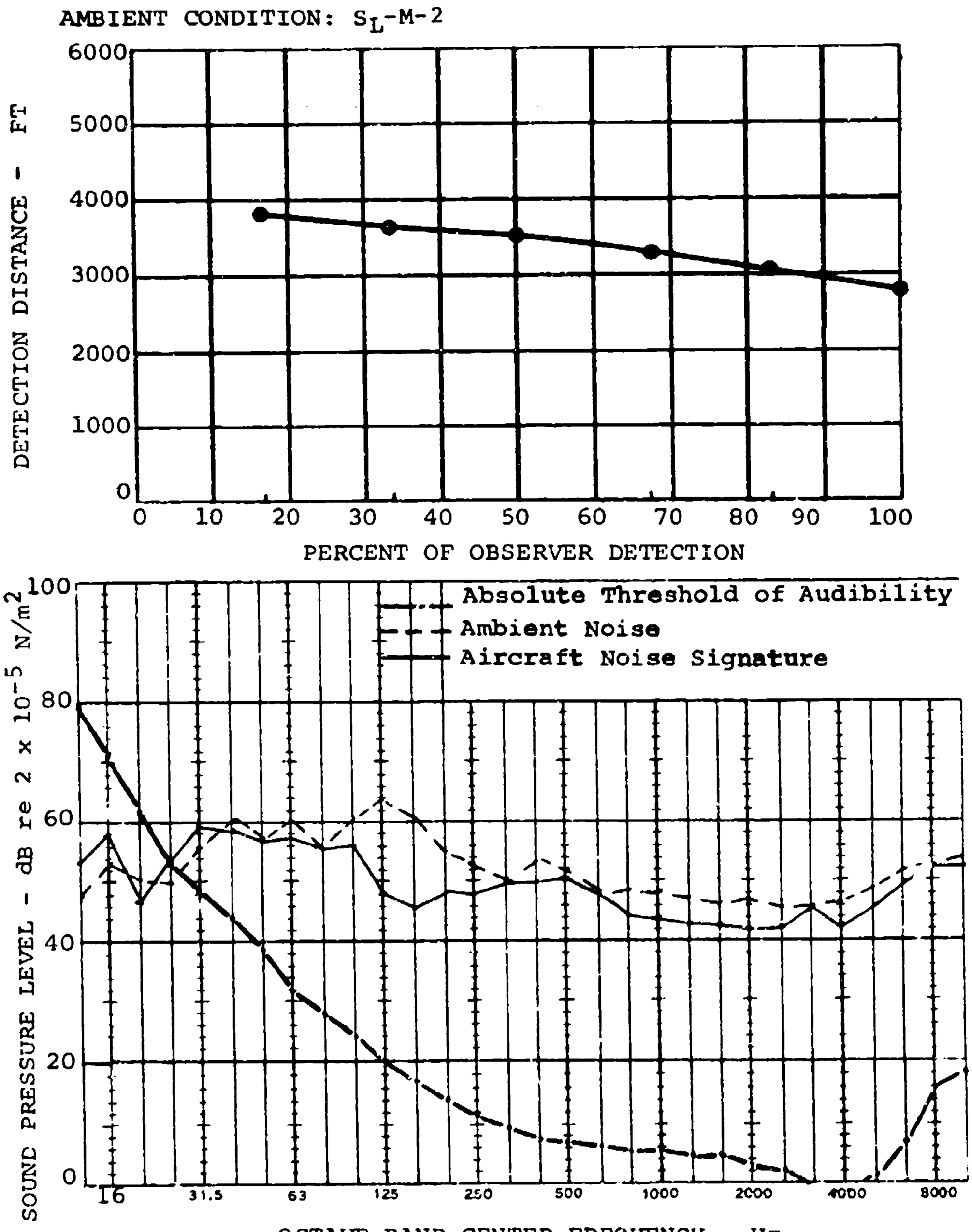


Figure 37. Observation and Acoustical Data - Run 20.

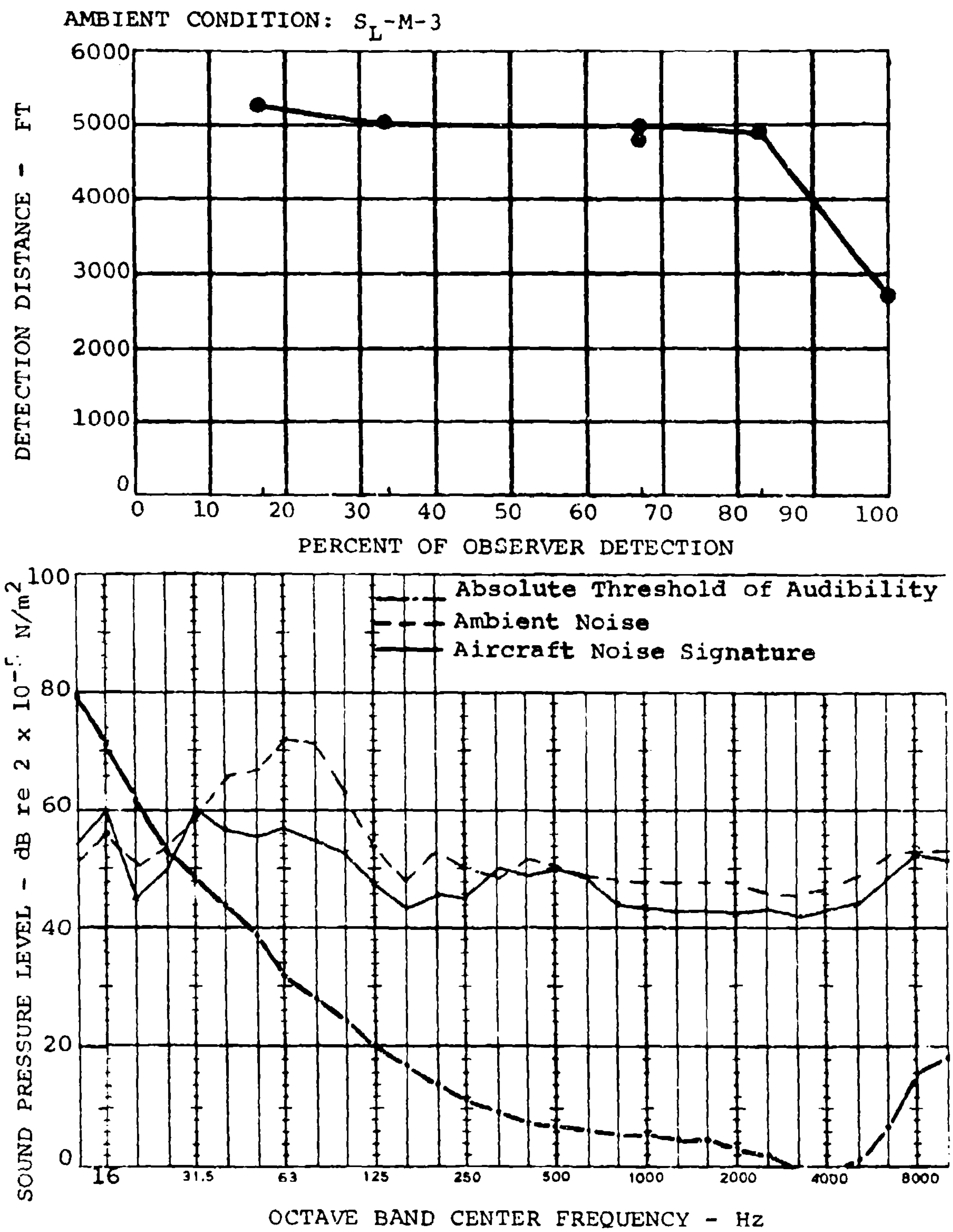
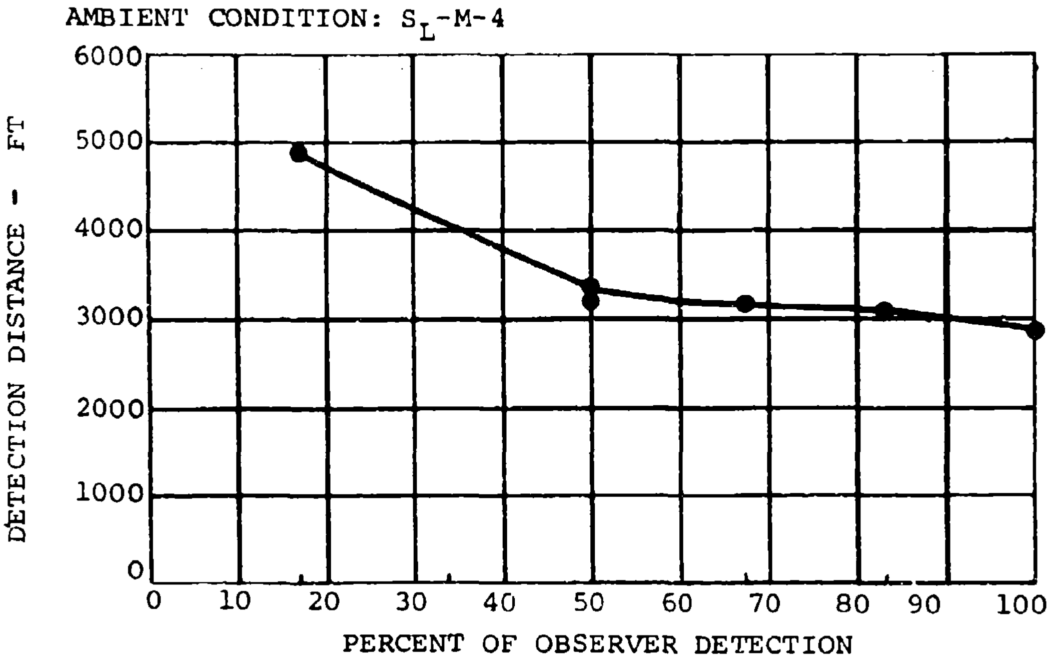


Figure 38. Observation and Acoustical Data -- Run 21.



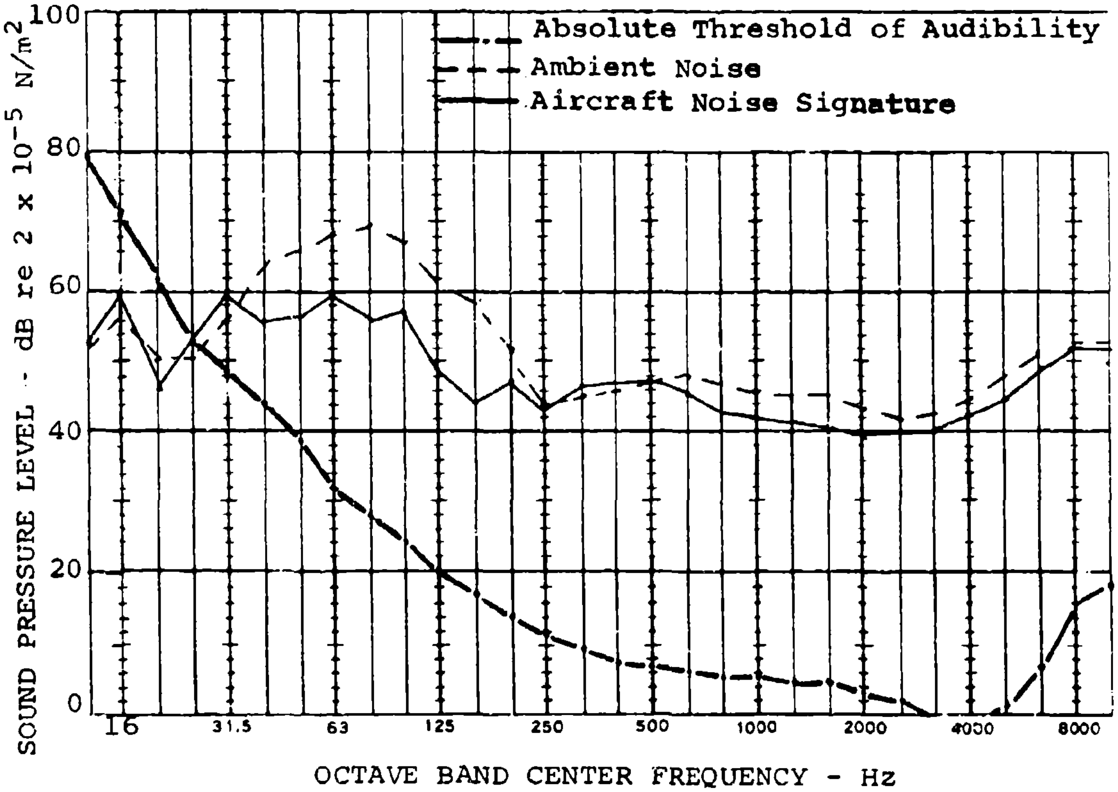
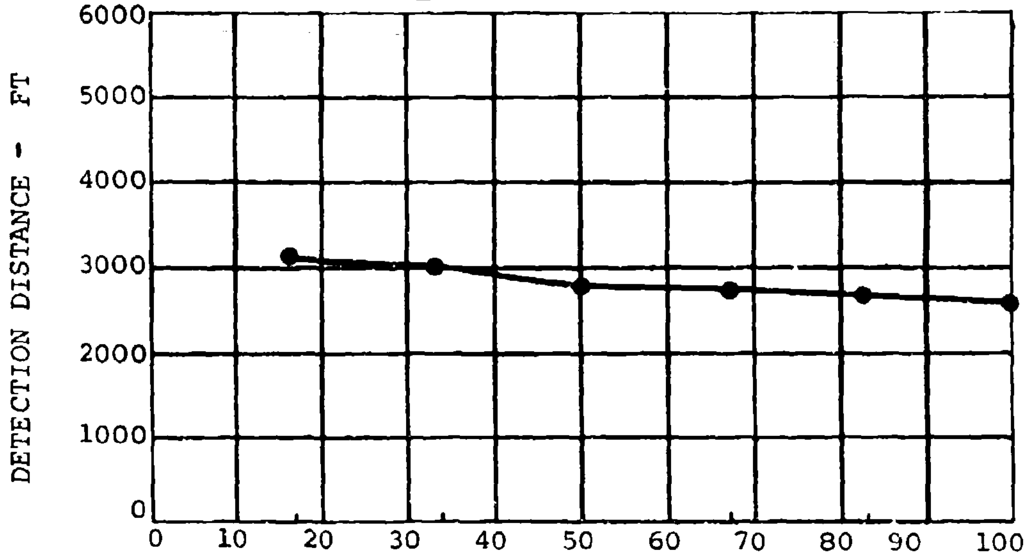


Figure 39. Observation and Acoustical Data - Run 22.

AMBIENT CONDITION: S_L-M-5



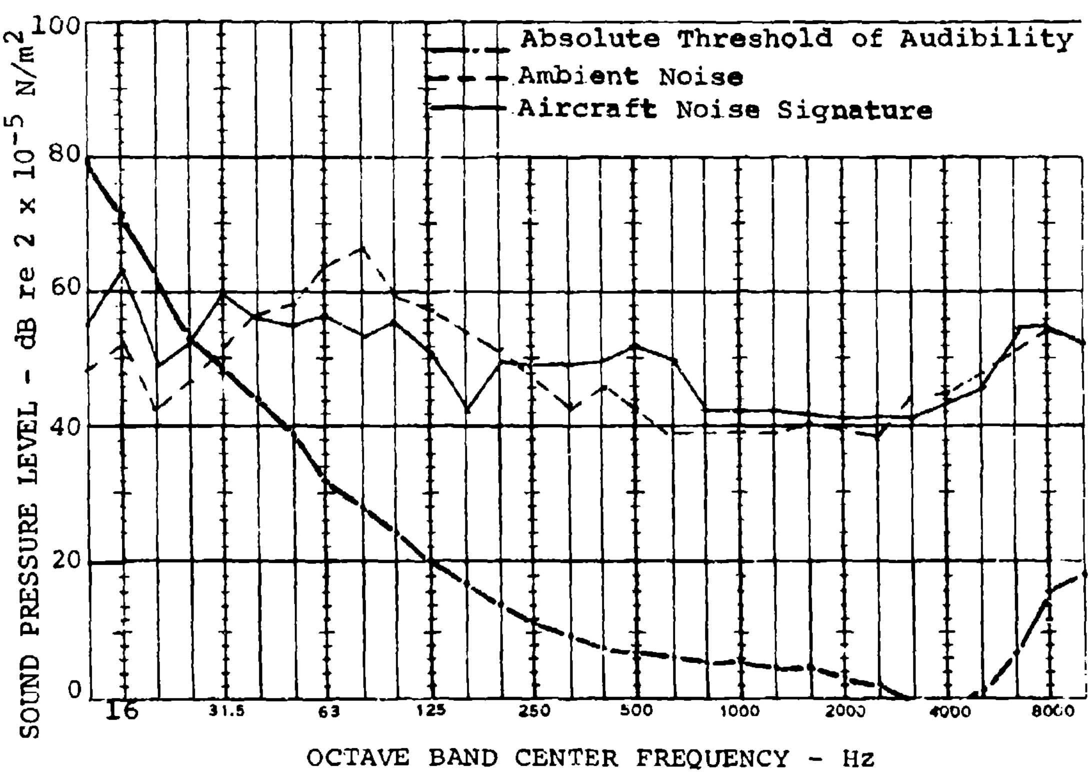


Figure 40. Observation and Acoustical Data - Run 23.

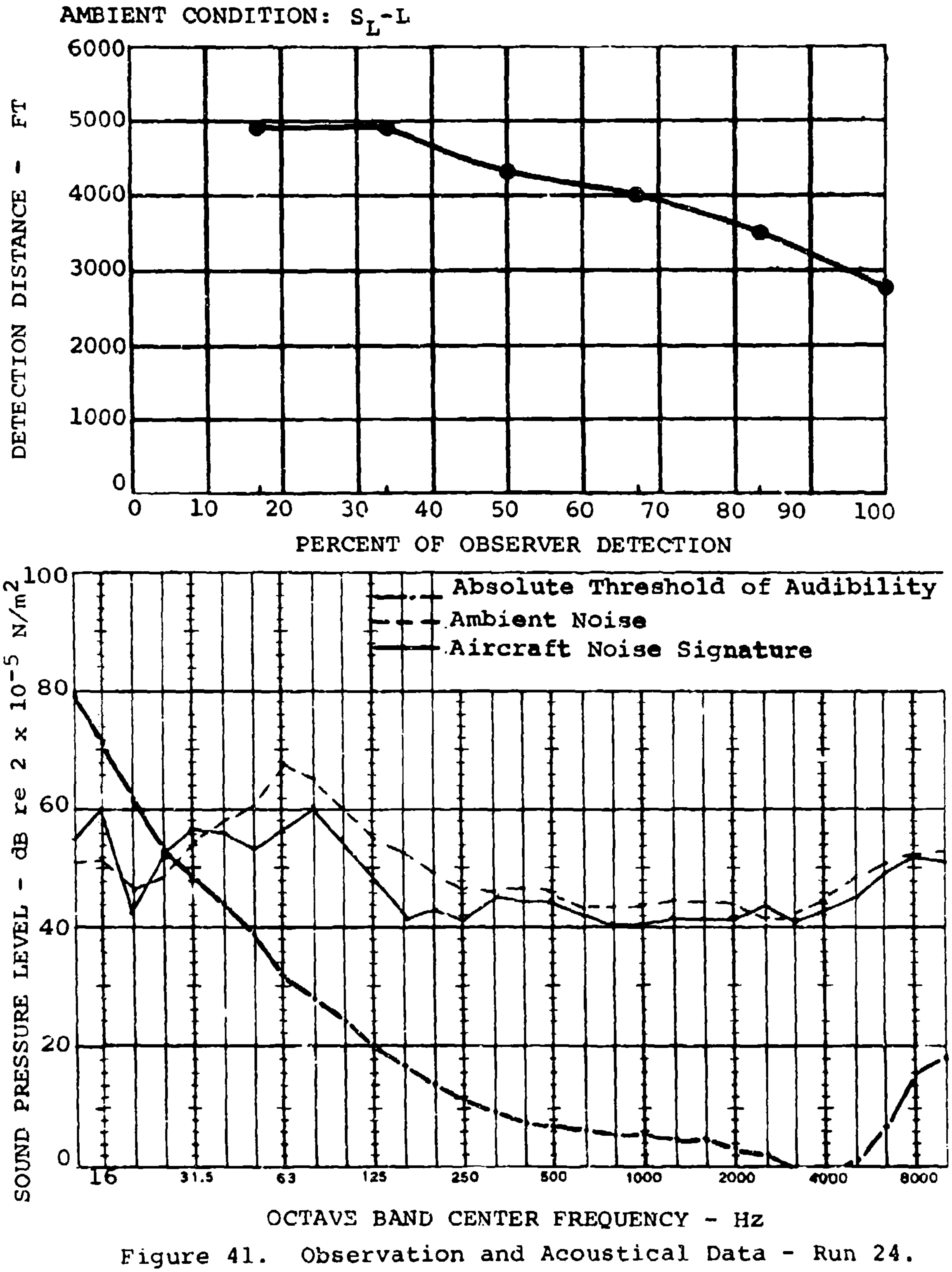


Figure 41. Observation and Acoustical Data - Run 24.

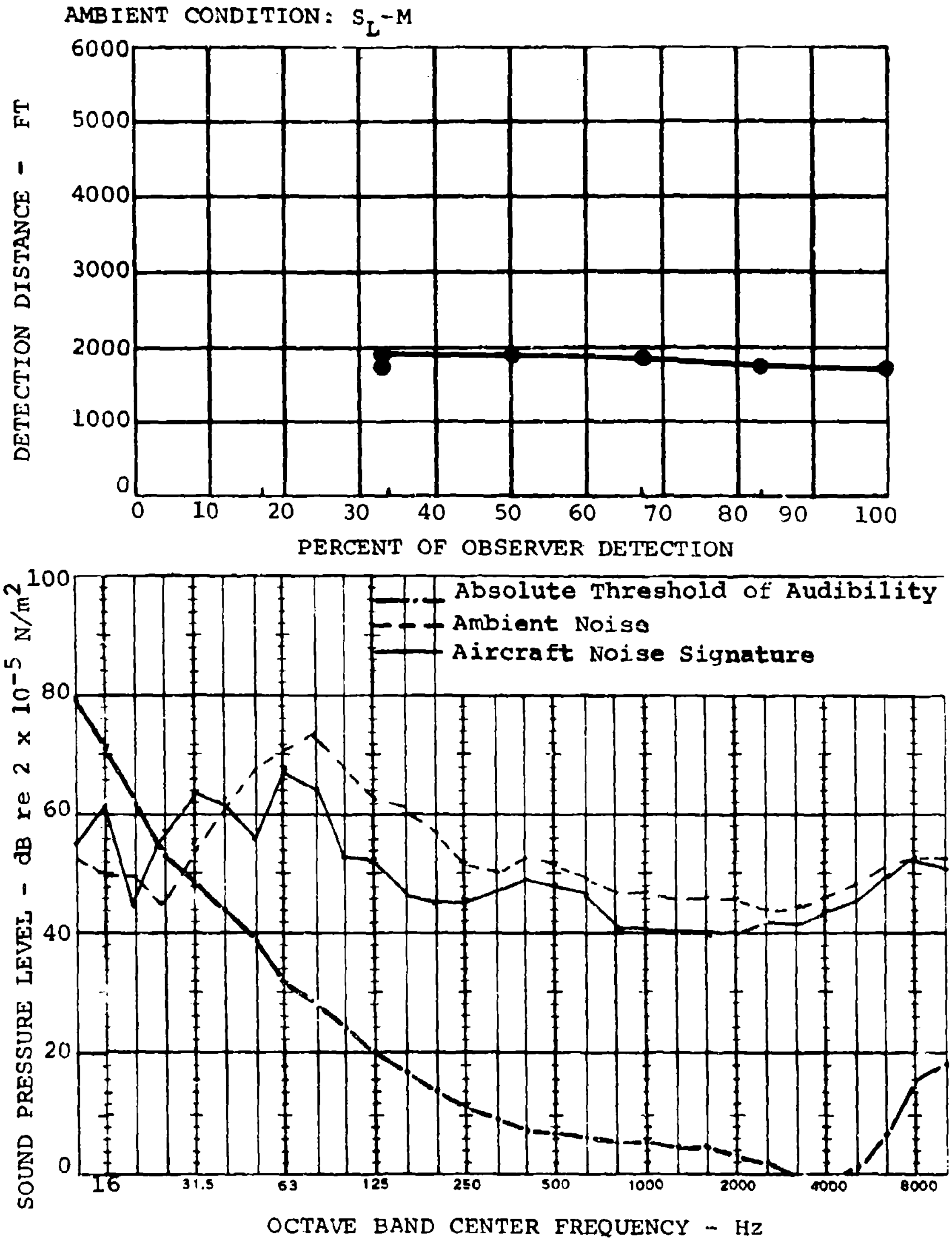


Figure 42. Observation and Acoustical Data - Run 25.

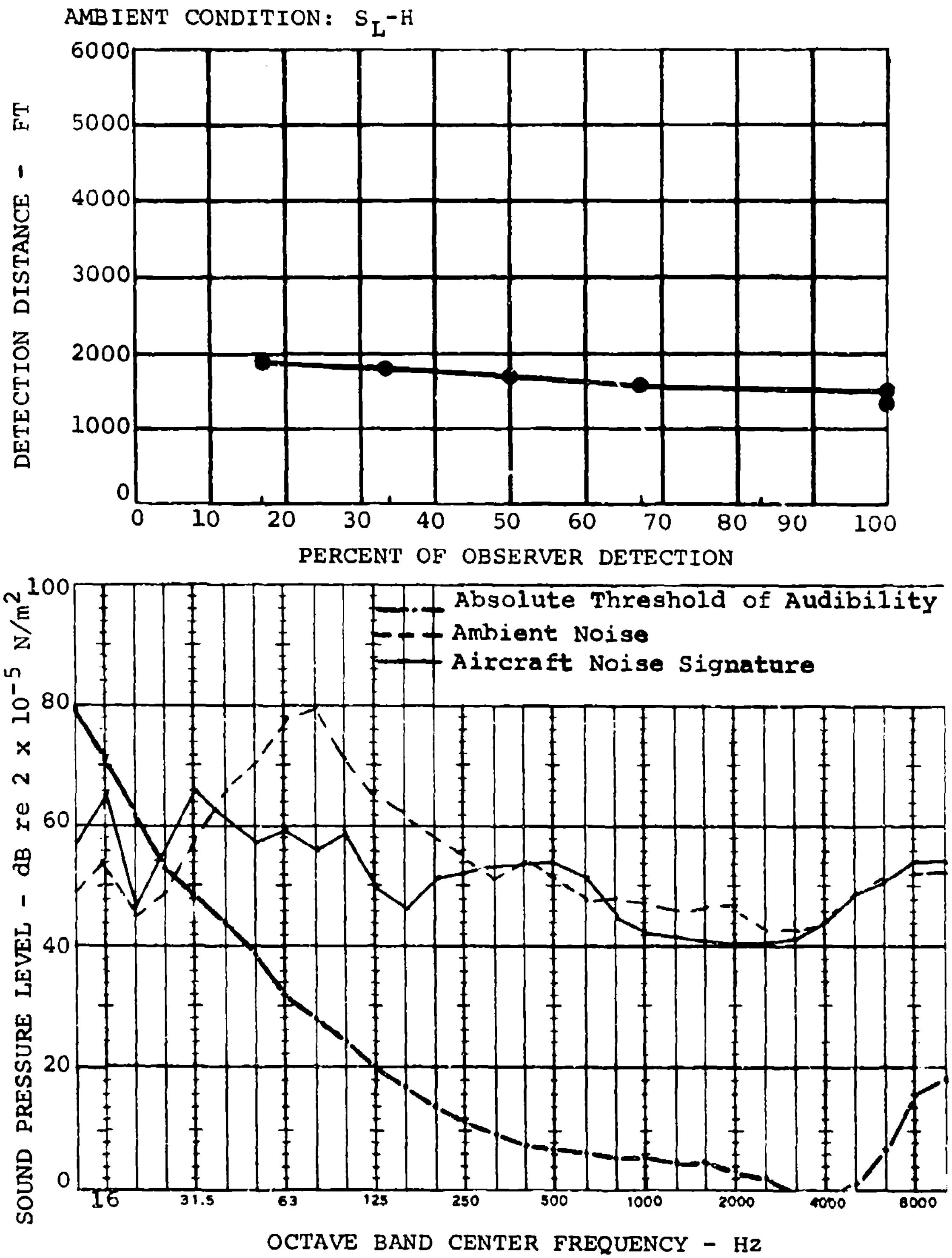


Figure 43. Observation and Acoustical Data - Run 26.

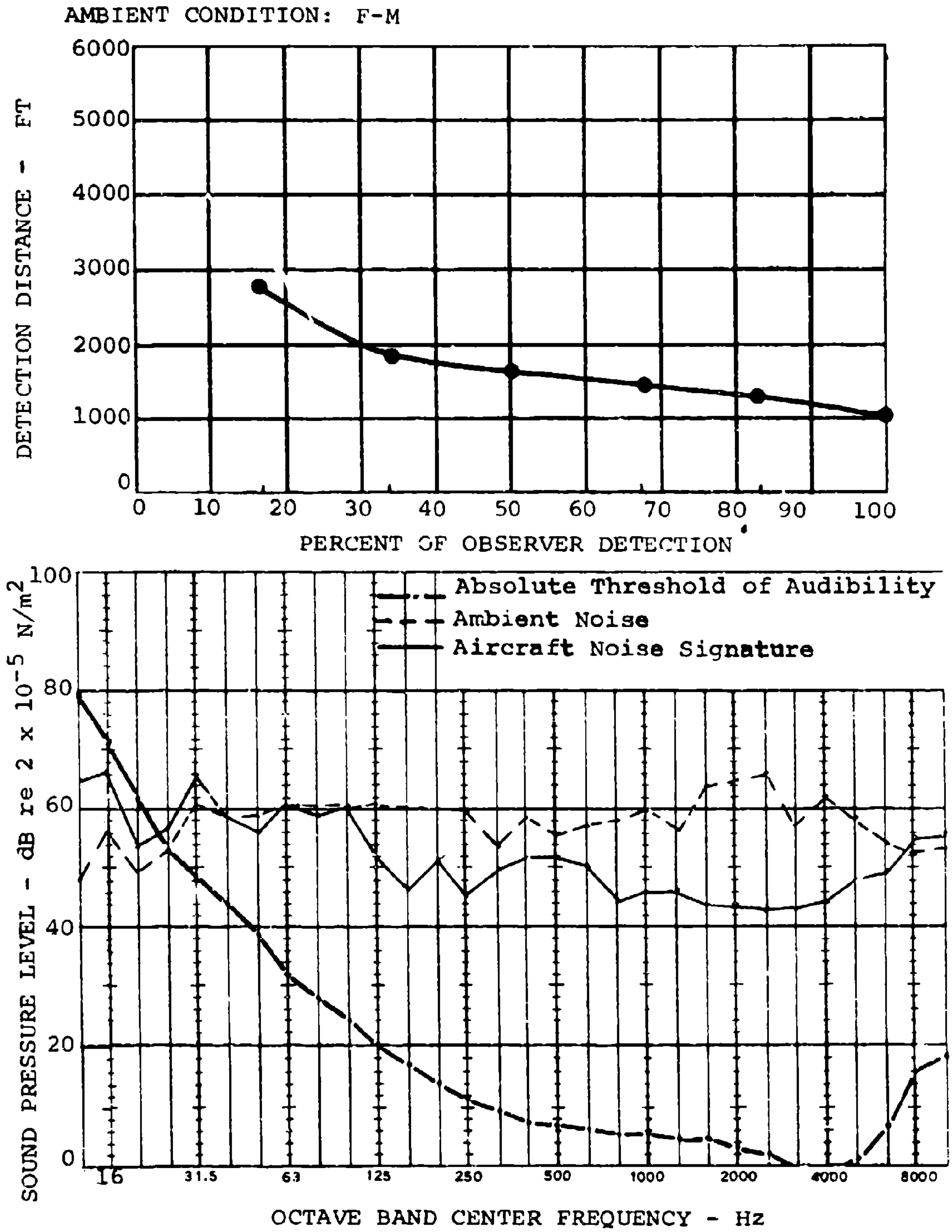


Figure 44. Observation and Acoustical Data - Run 27.

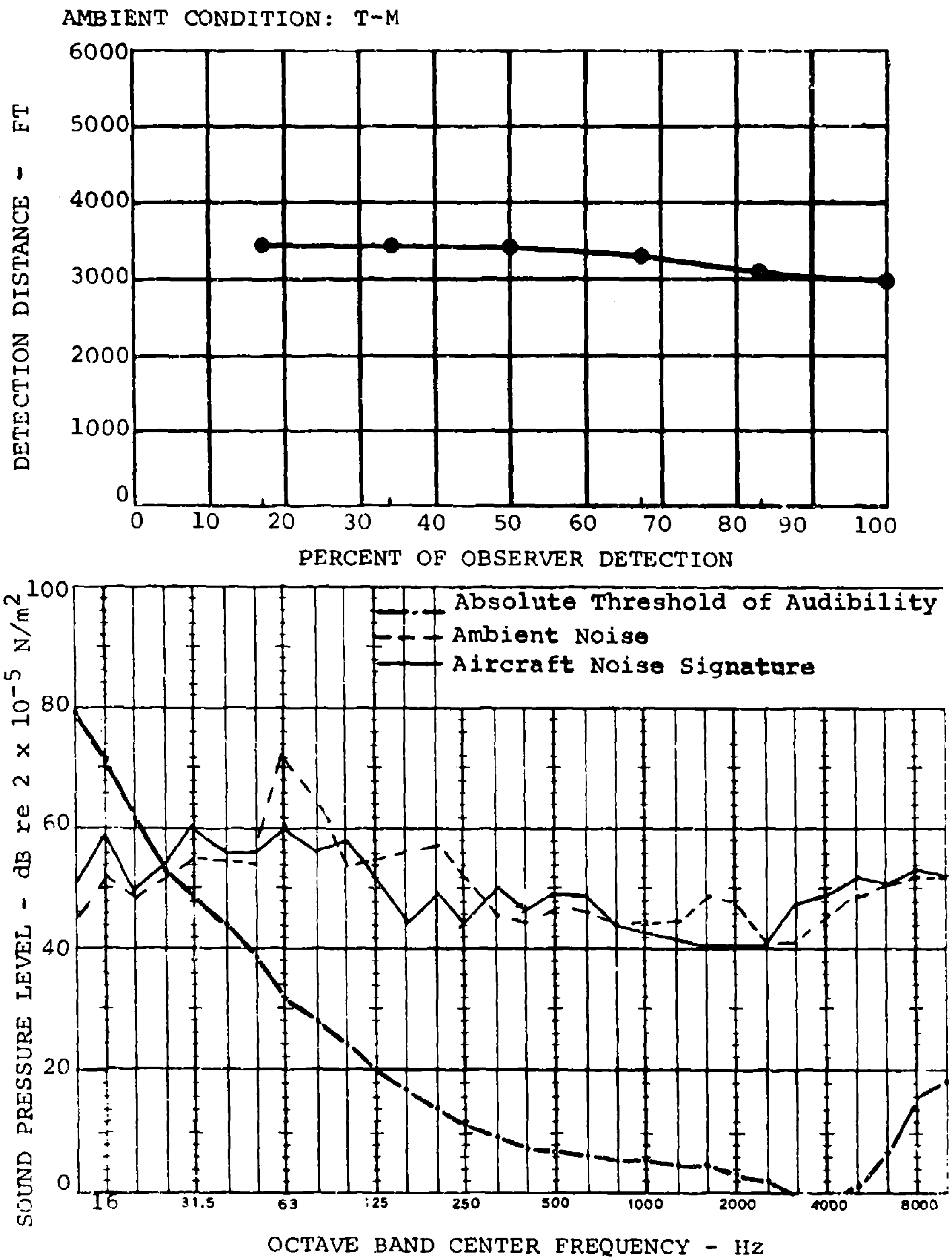


Figure 45. Observation and Acoustical Data - Run 29.

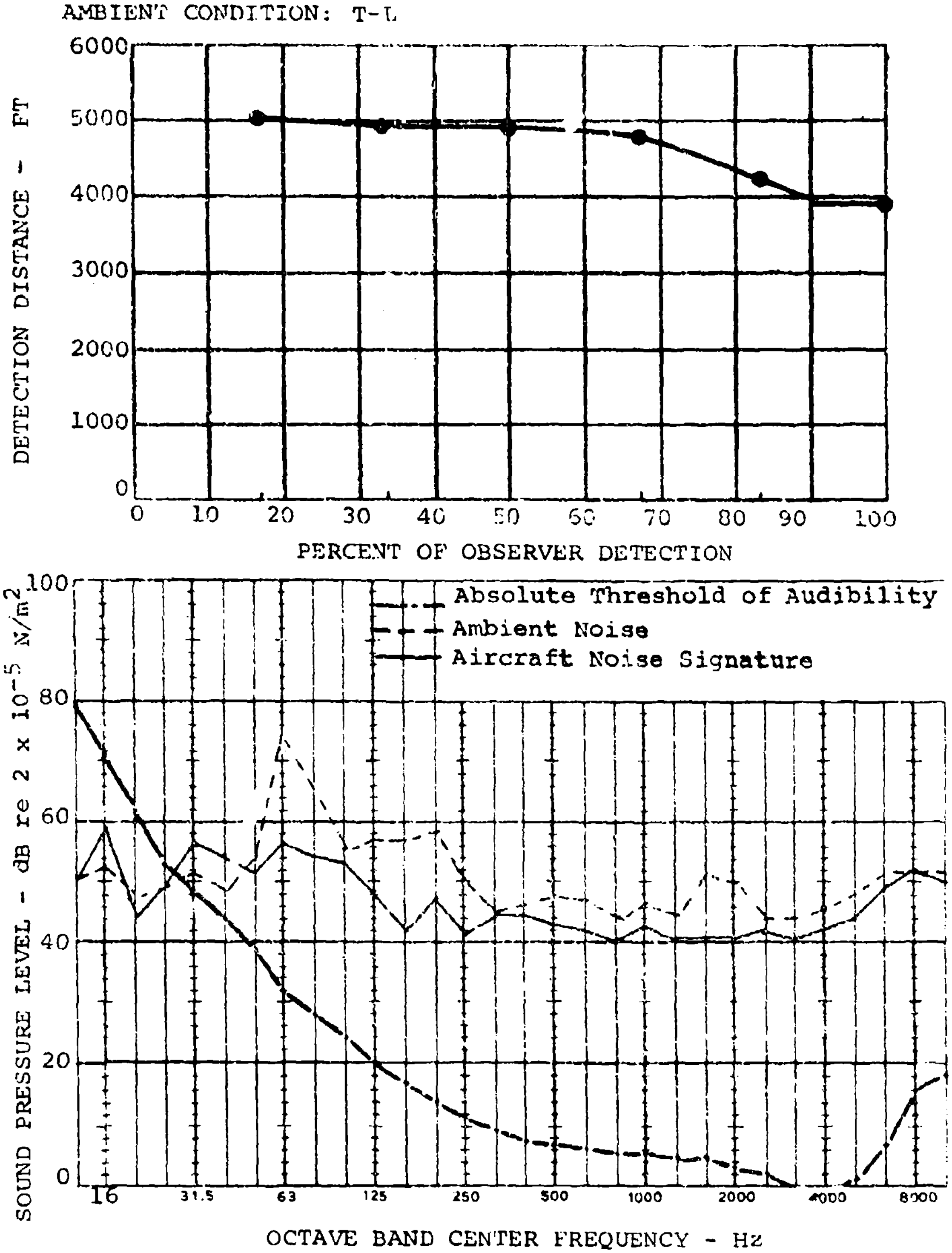


Figure 46. Observation and Acoustical Data - Run 30.

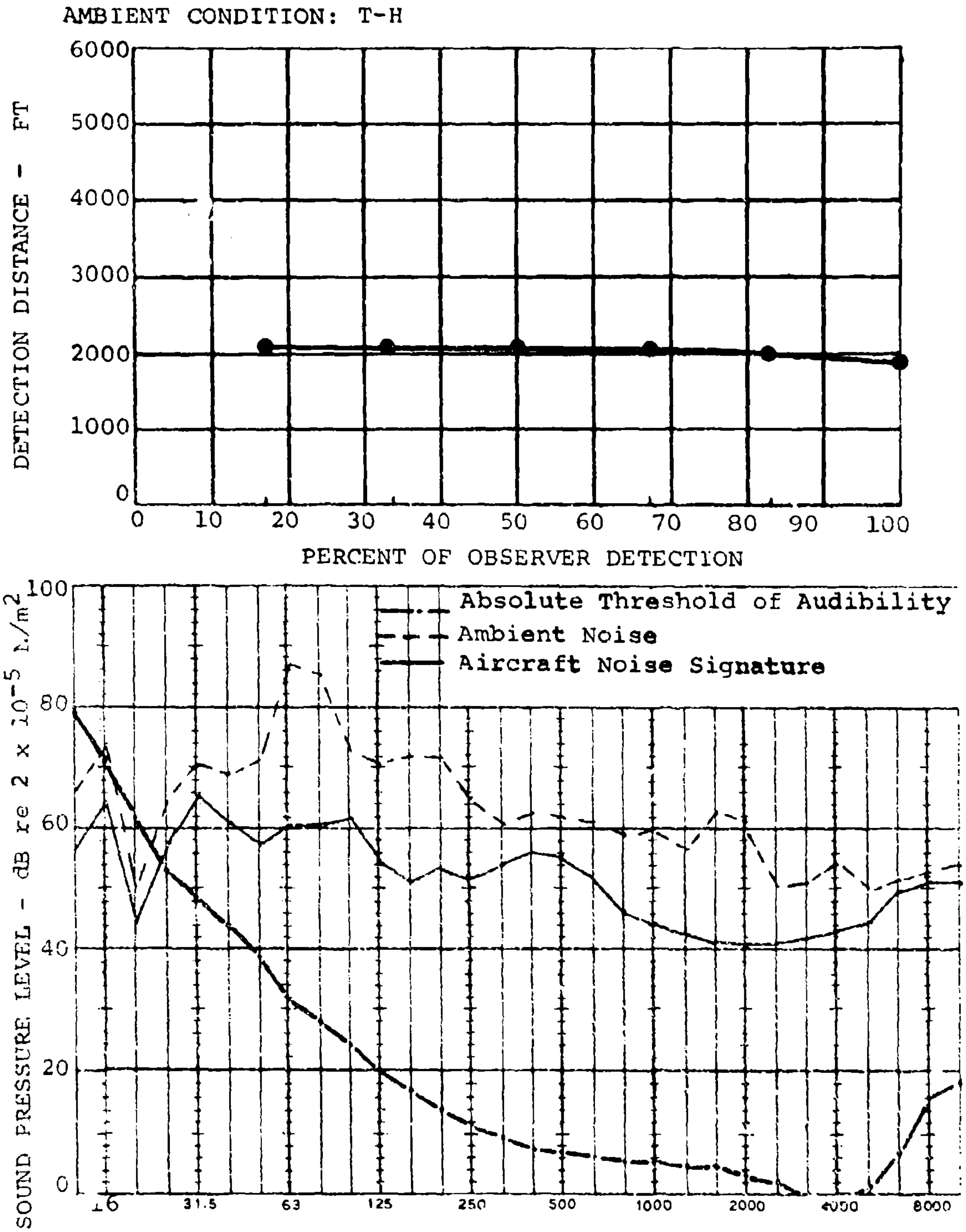


Figure 47. Observation and Acoustical Data - Run 31.

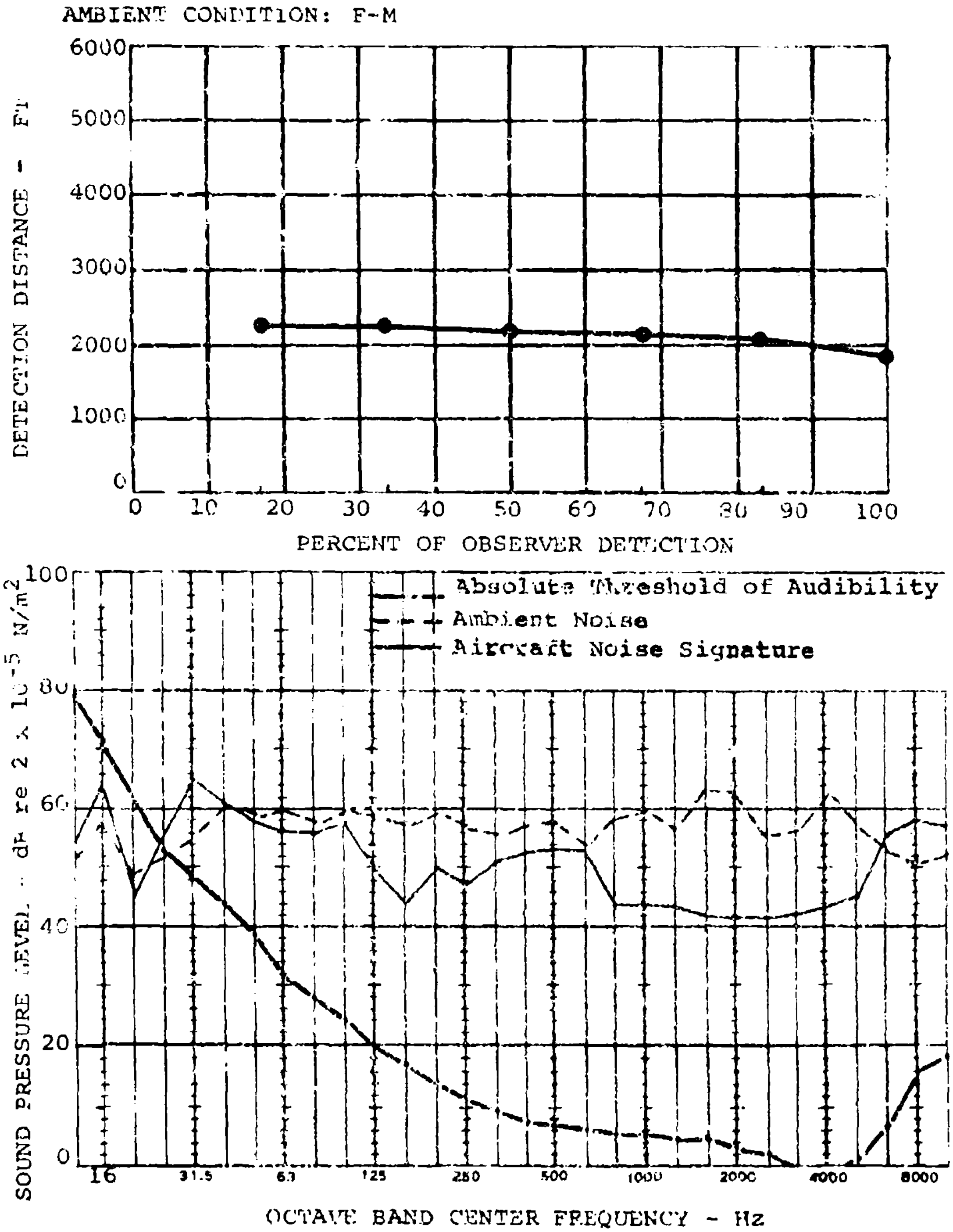


Figure 48. Observation and Acoustical Data - Run 32.

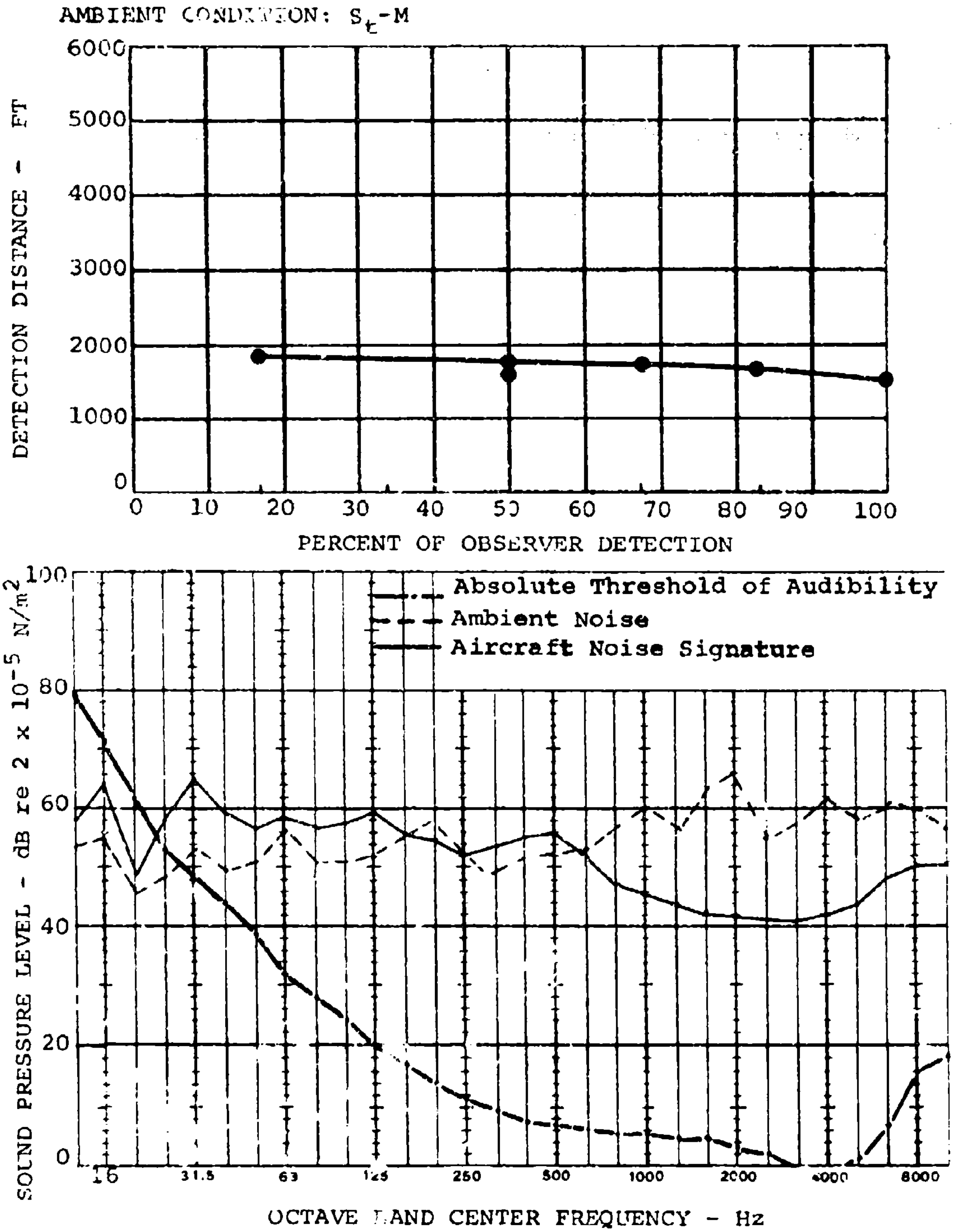


Figure 49. Observation and Acoustical Data - Run 33.

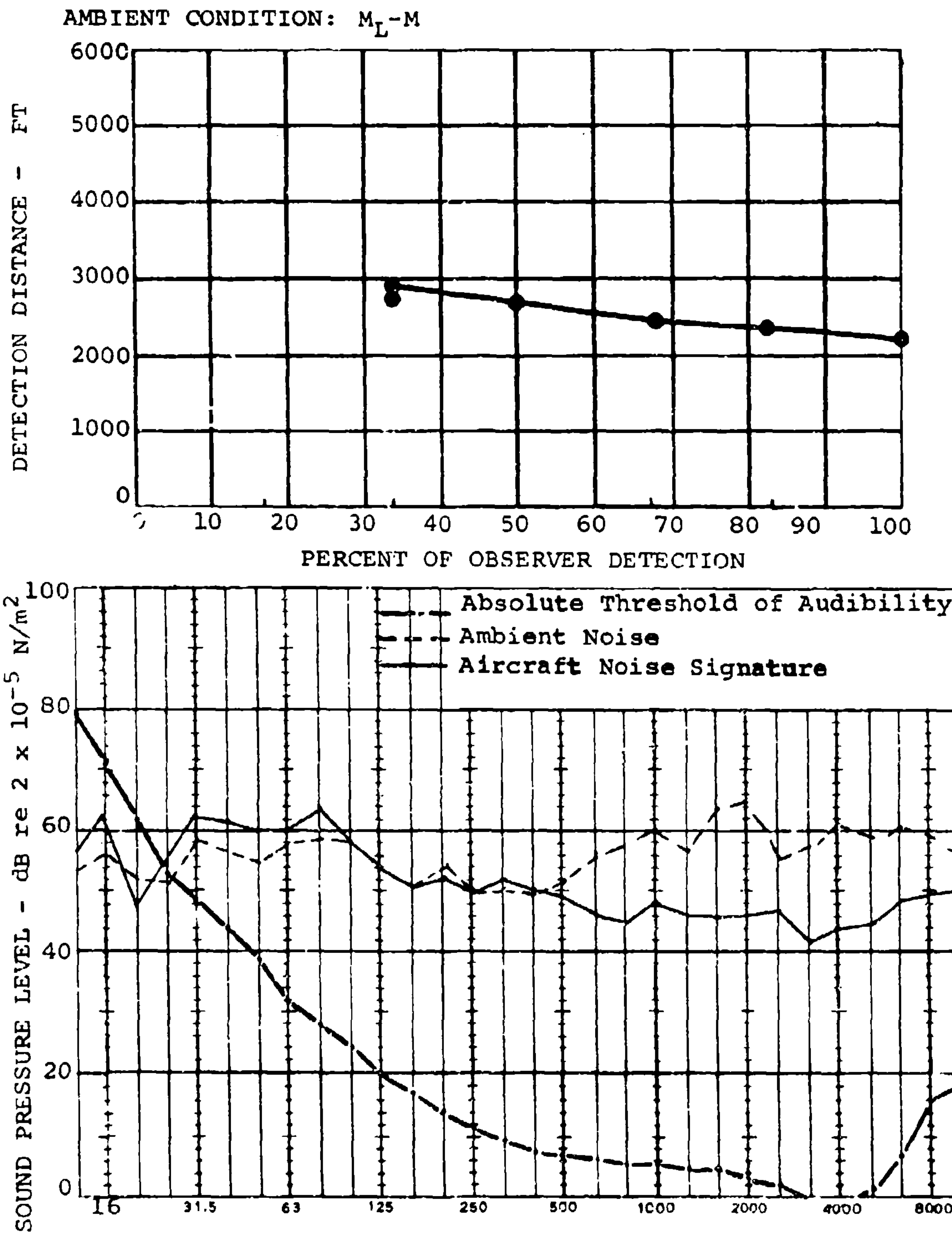


Figure 50. Observation and Acoustical Data - Run 34.

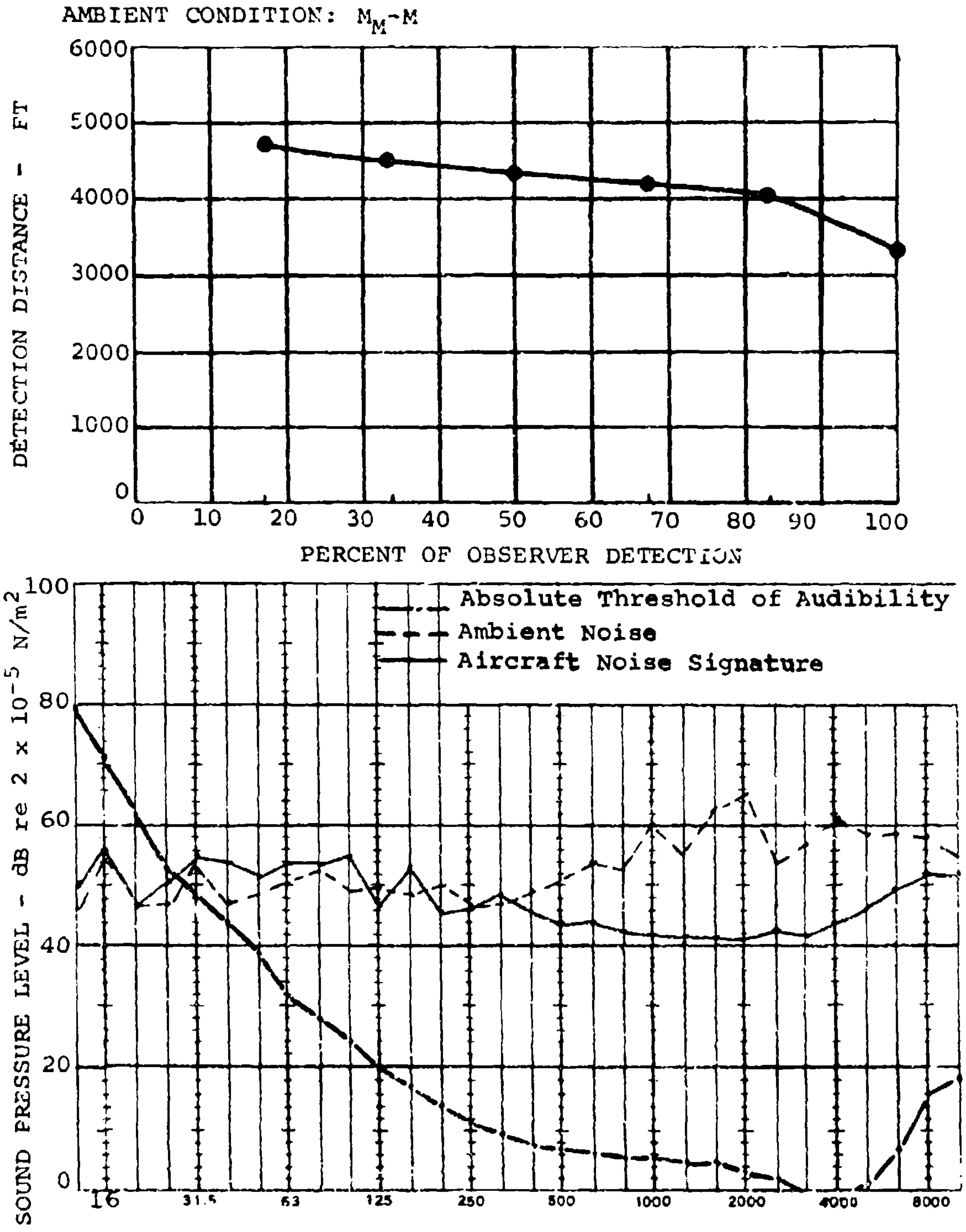


Figure 51. Observation and Acoustical Data - Run 35.

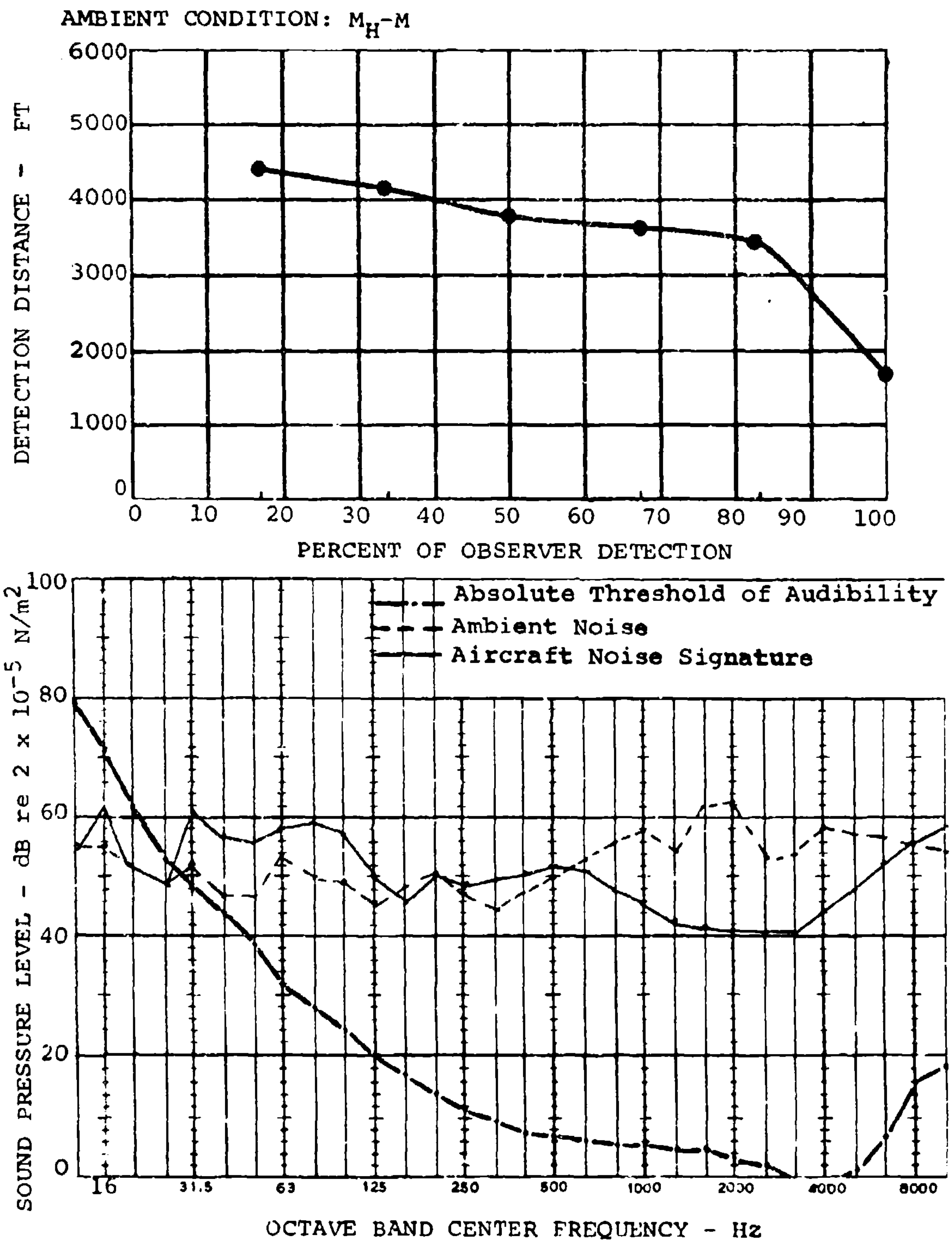


Figure 52. Observation and Acoustical Data - Run 36.

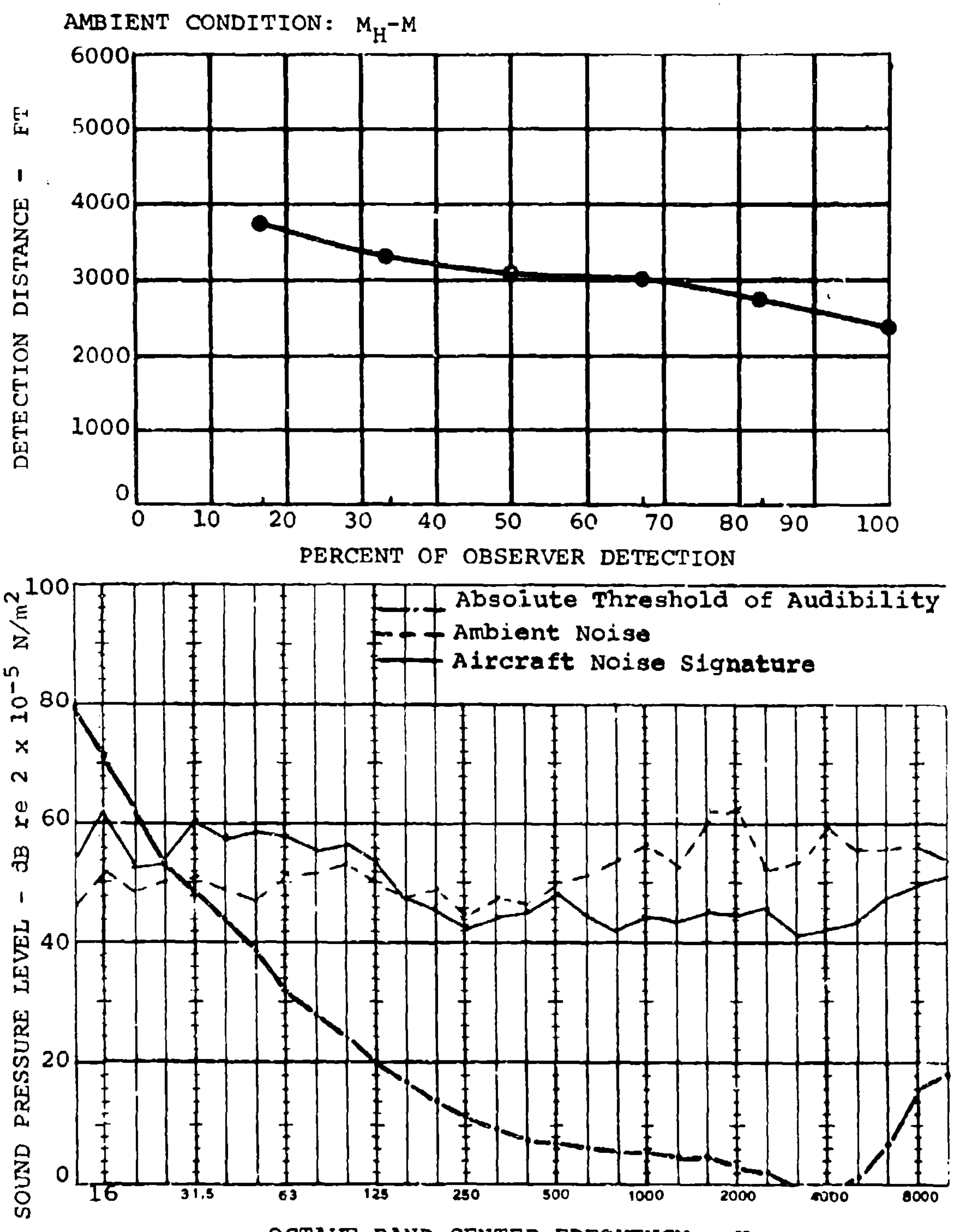


Figure 53. Observation and Acoustical Data - Run 37.

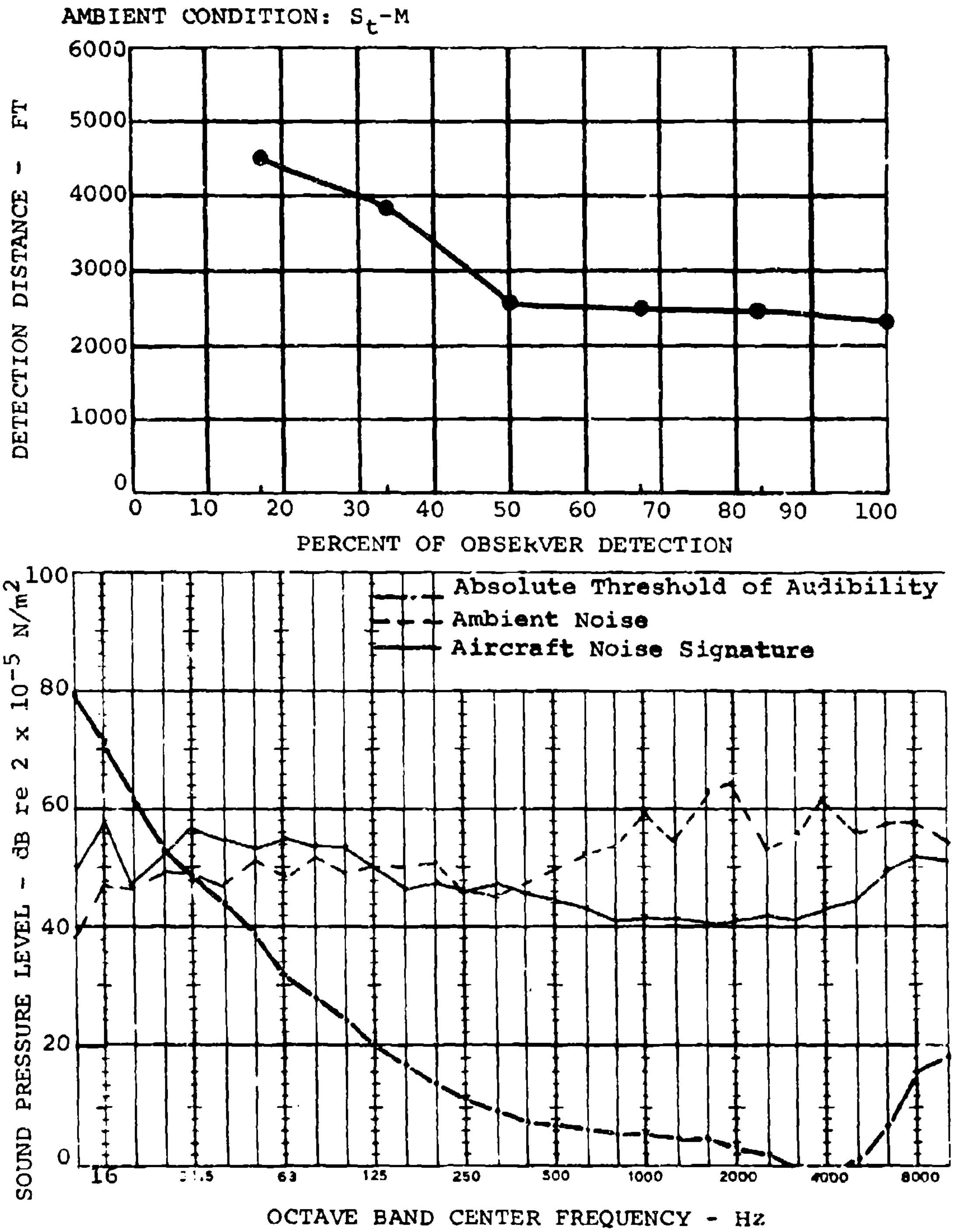


Figure 54. Observation and Acoustical Data - Run 38.

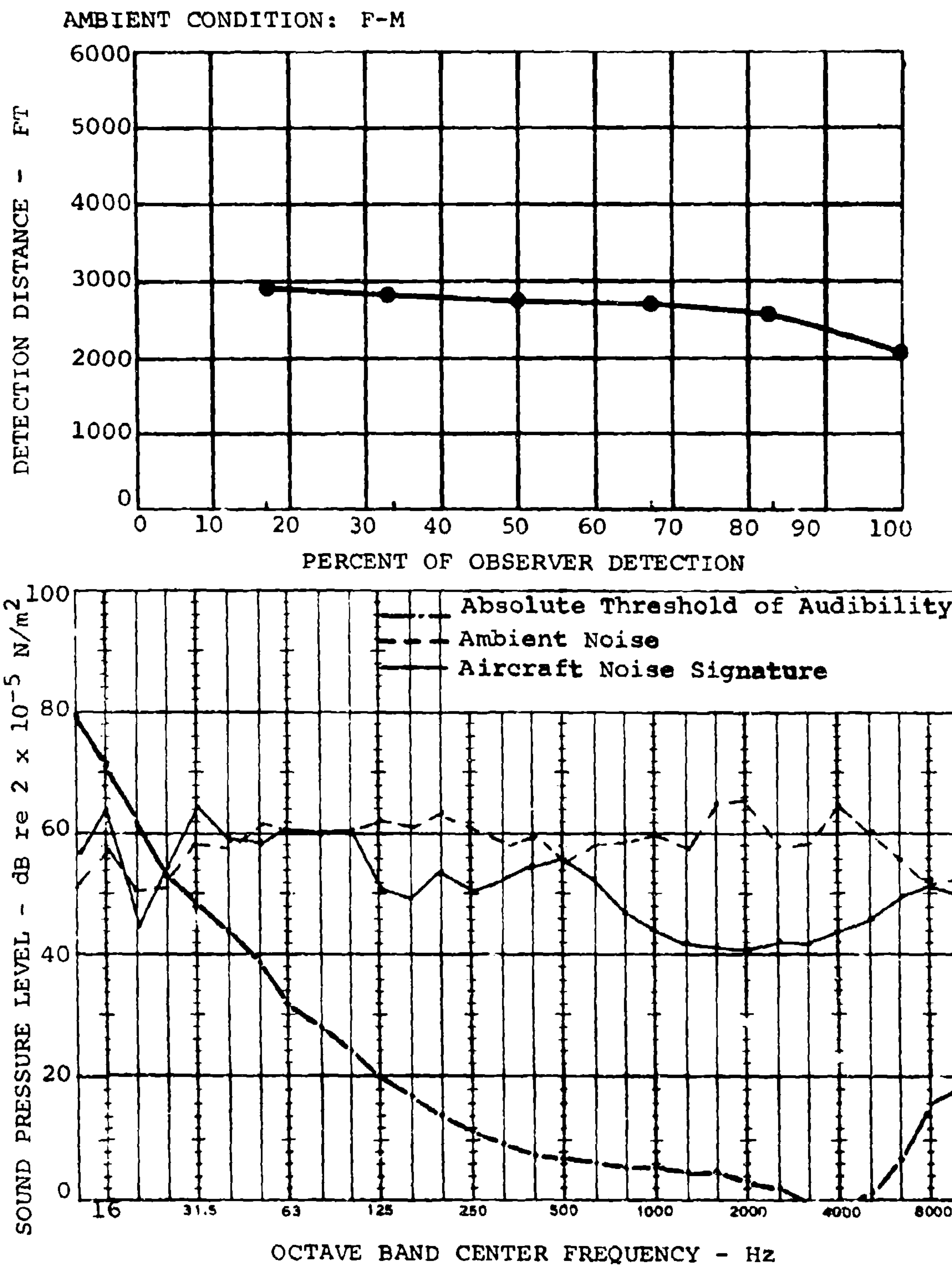


Figure 55. Observation and Acoustical Data - Run 41.

APPENDIX III
GRAPHIC RELATIONSHIP OF AIRCRAFT AND AMBIENT SOUND PRESSURE LEVELS

Contained in this appendix are bar graphs of the calculated sound pressure levels (aircraft - ambient) for each 1/3 octave band frequency and for each test run conducted. Two sound pressure levels are shown at each frequency. The upper level was calculated from the aircraft noise signature at the minimum detection distance, or when all six observers had definitely detected the helicopter. The lower level was calculated from the aircraft noise signature at the maximum detection distance or when the first observer indicated definite detection. This graphic display of the data shows which frequency band set detection* and also the relationship of the aircraft and ambient sound pressure levels throughout the frequency spectrum.

The same ambient condition codes that were shown in Appendix II are used for identification of each graph.

*See explanation, Figure 11.

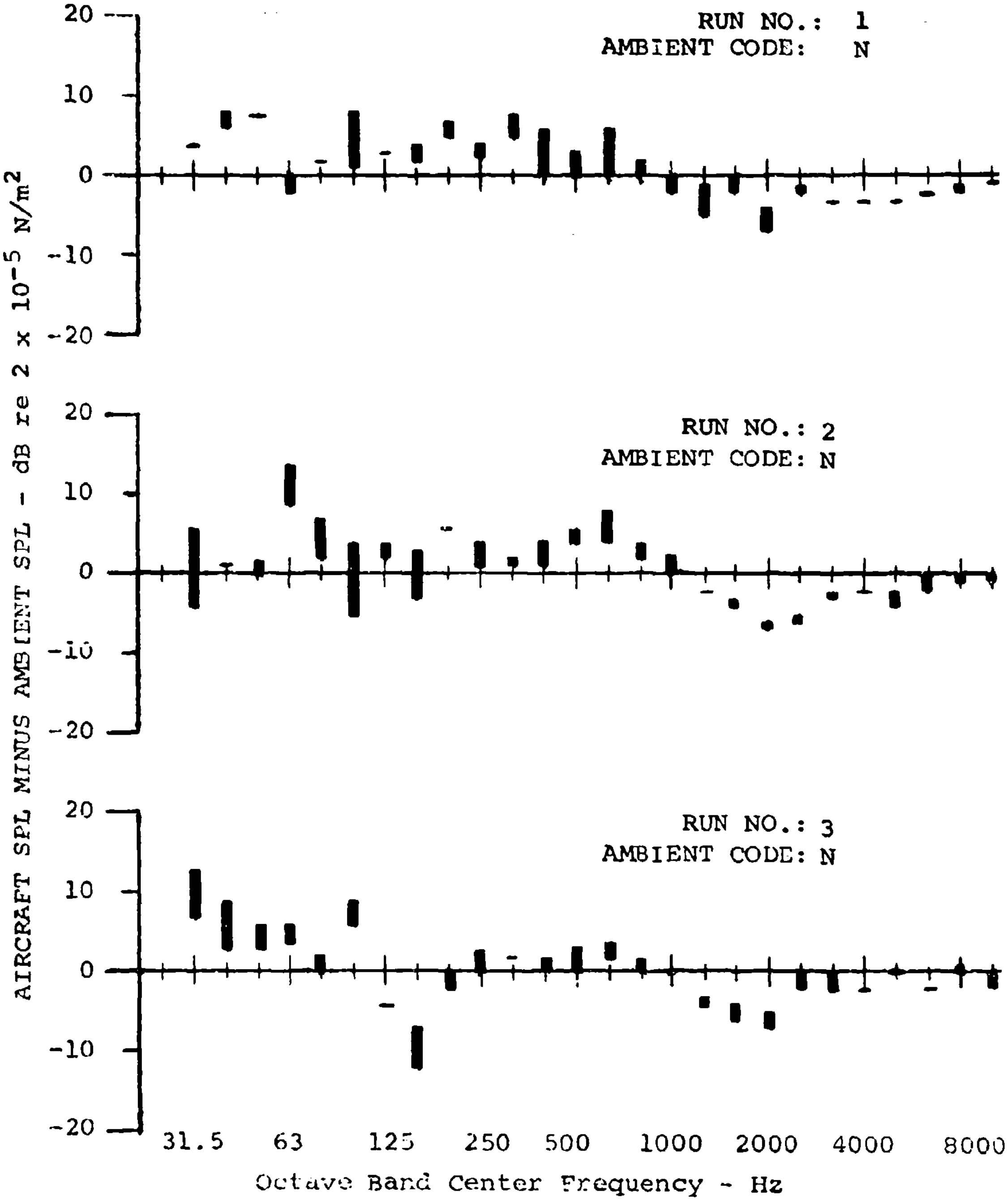


Figure 56. Detection Results With Natural Ambient.

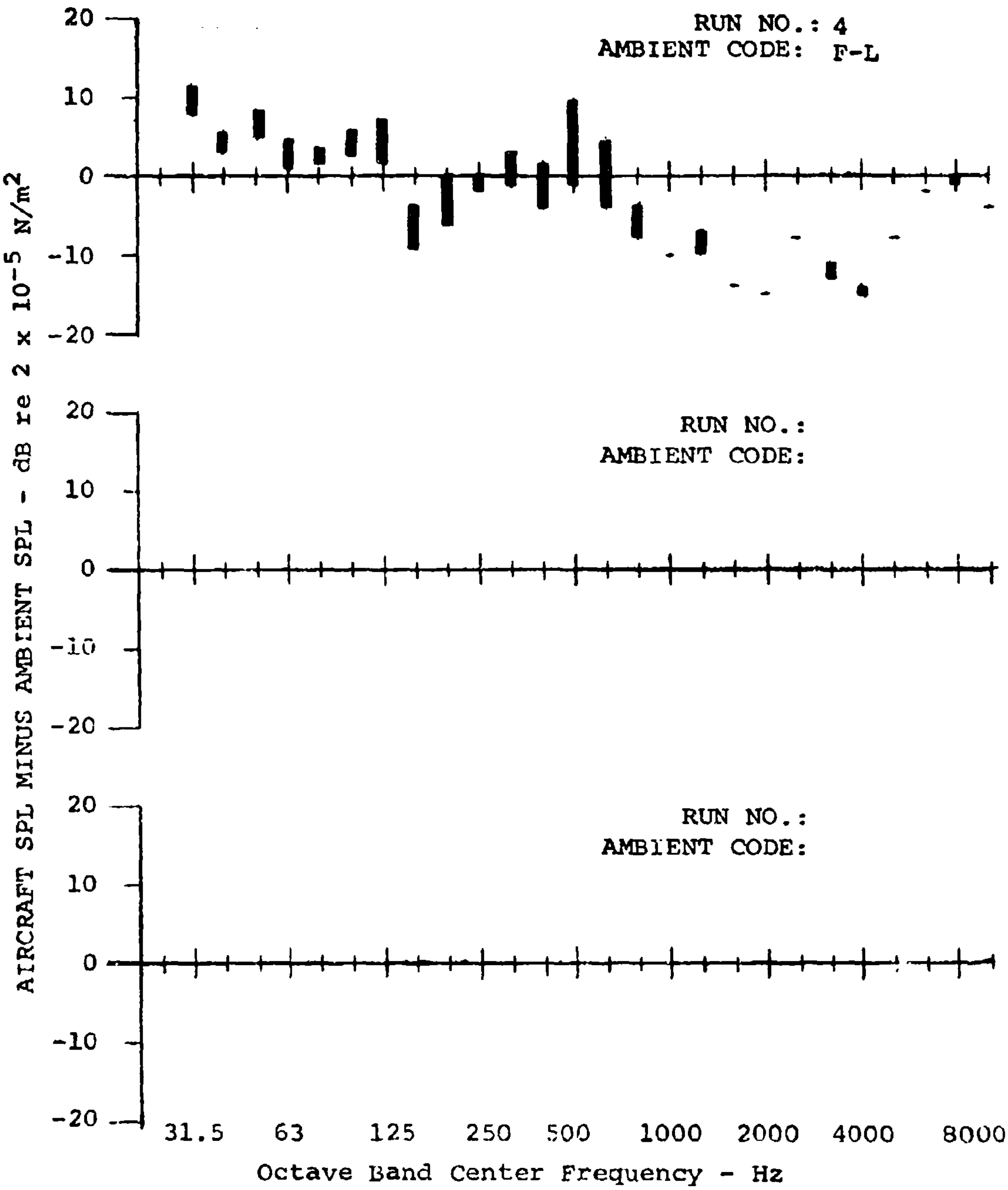


Figure 57. Detection Results With Flat, Low-Level Ambient.

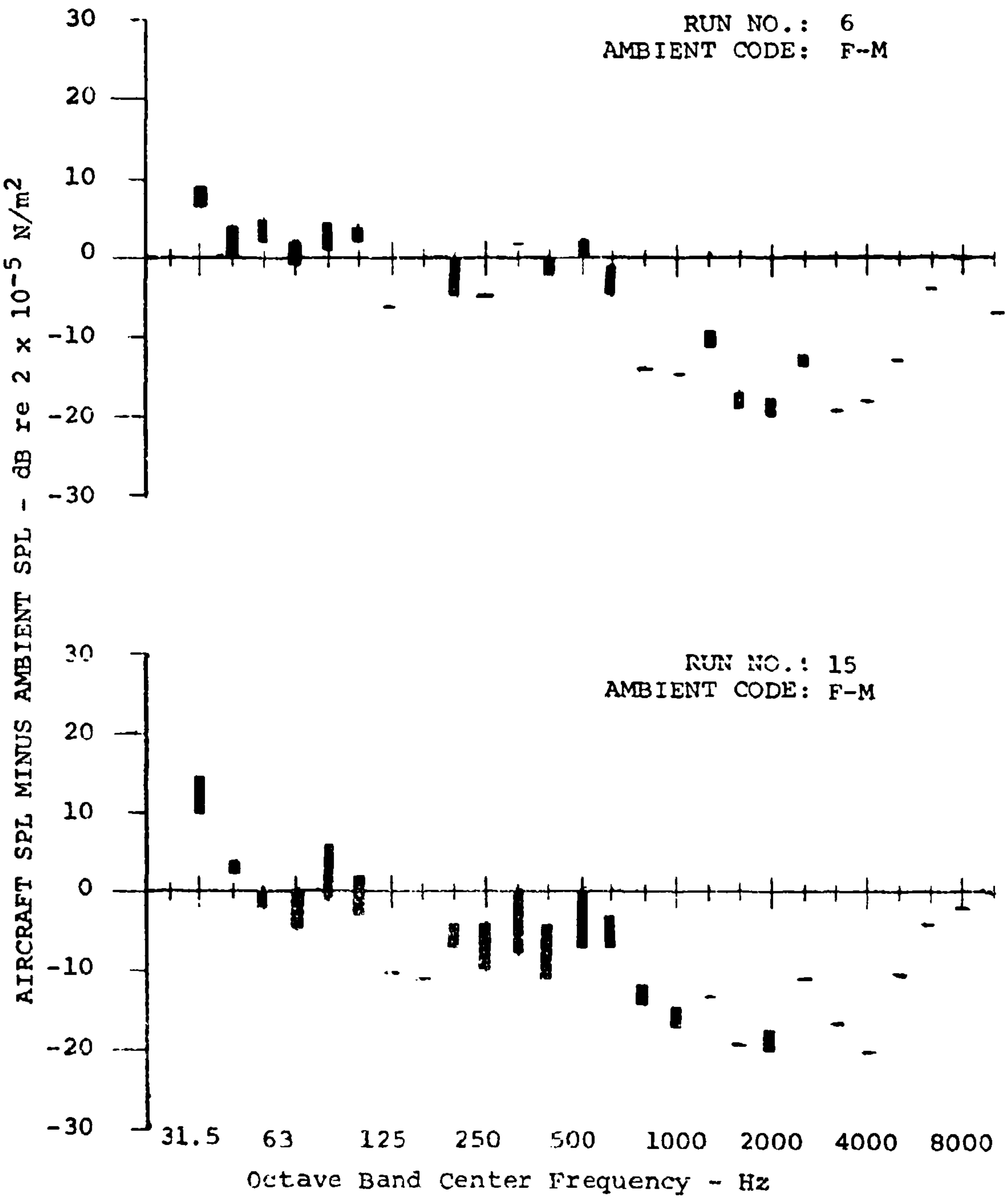


Figure 58. Detection Results With Flat, Medium-Level Ambient.

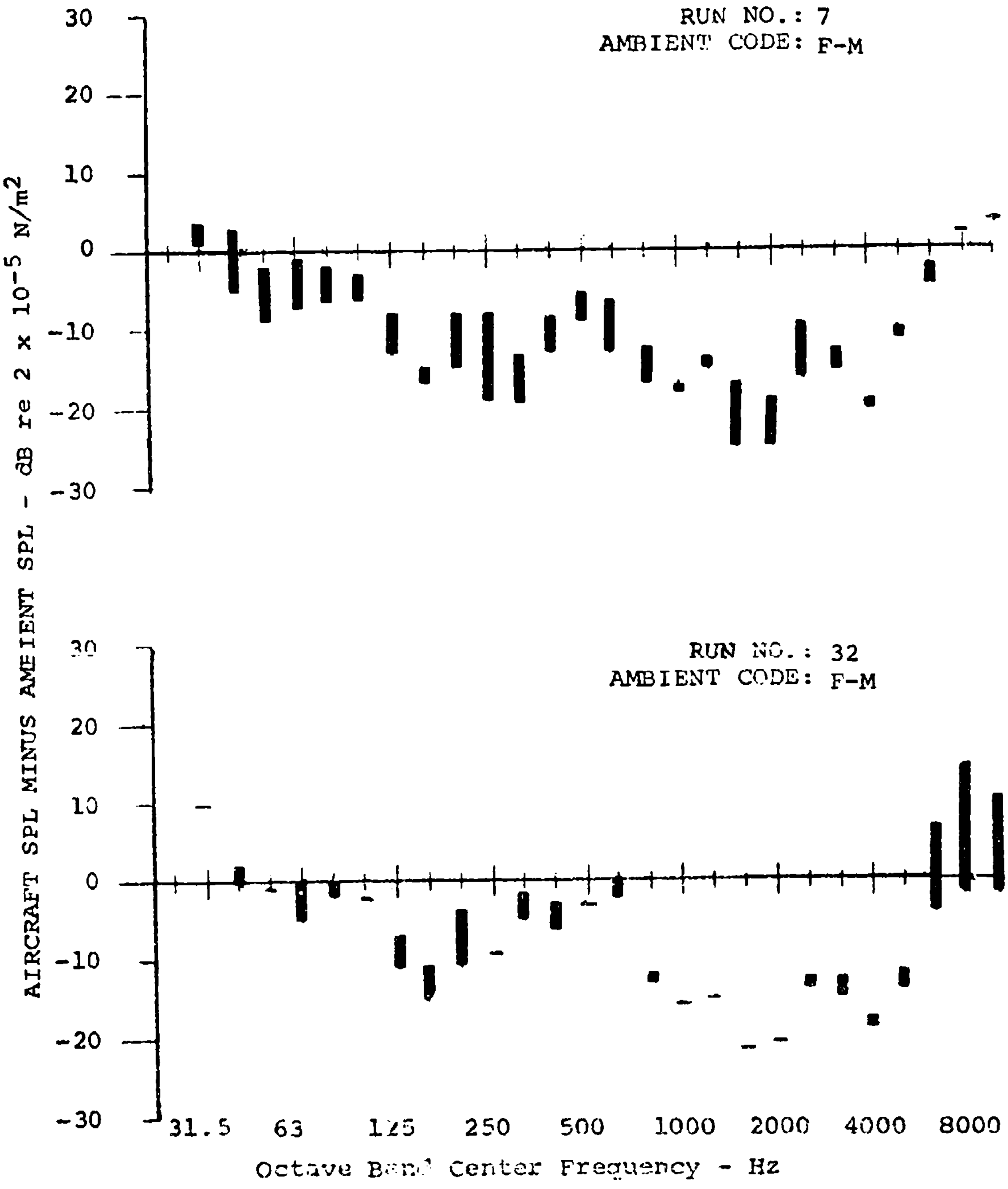


Figure 58. Continued.

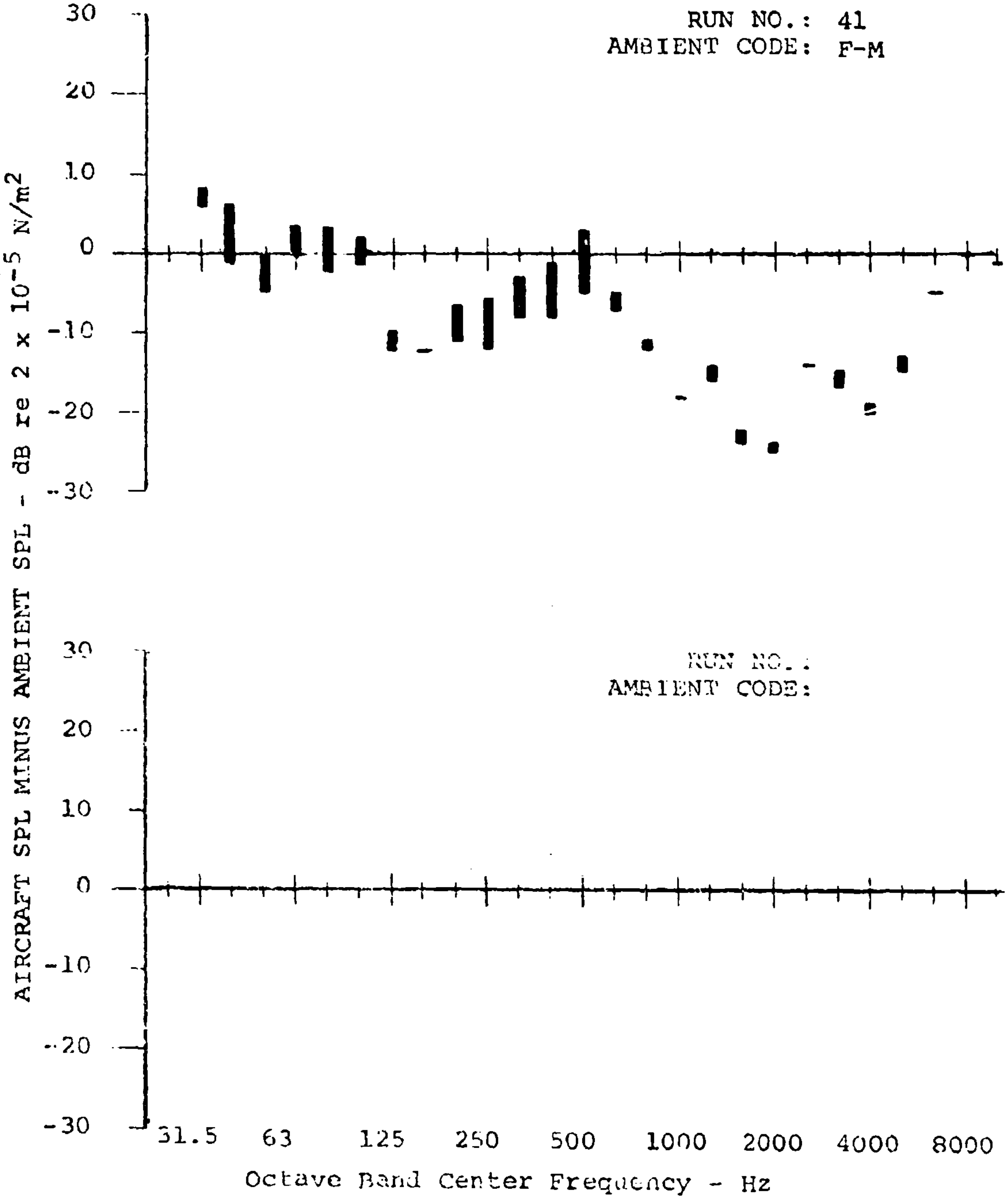


Figure 58. Continued.

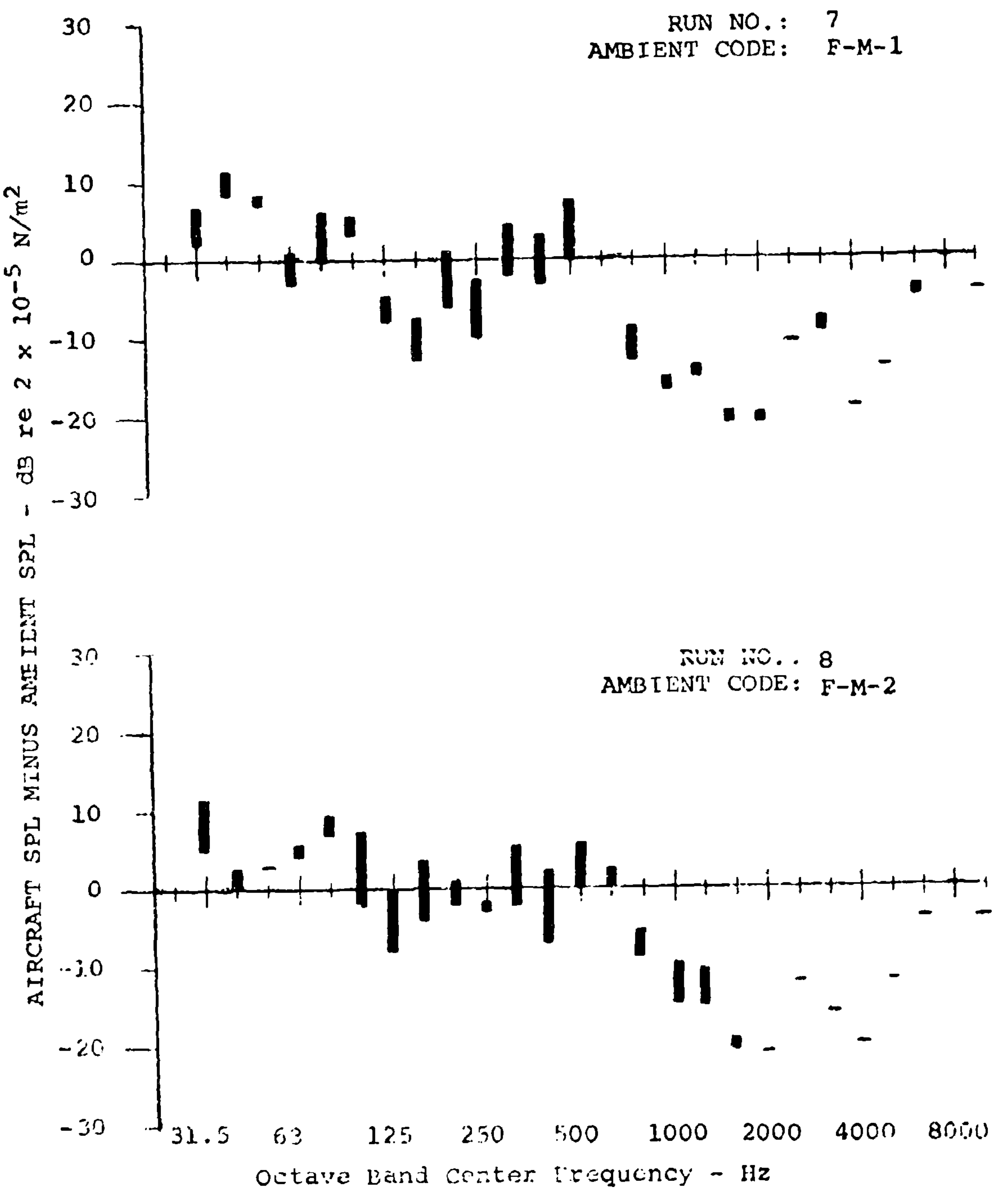


Figure 59. Detection Results With Flat, Medium-Level Ambient - Specific Octave Bands Removed.

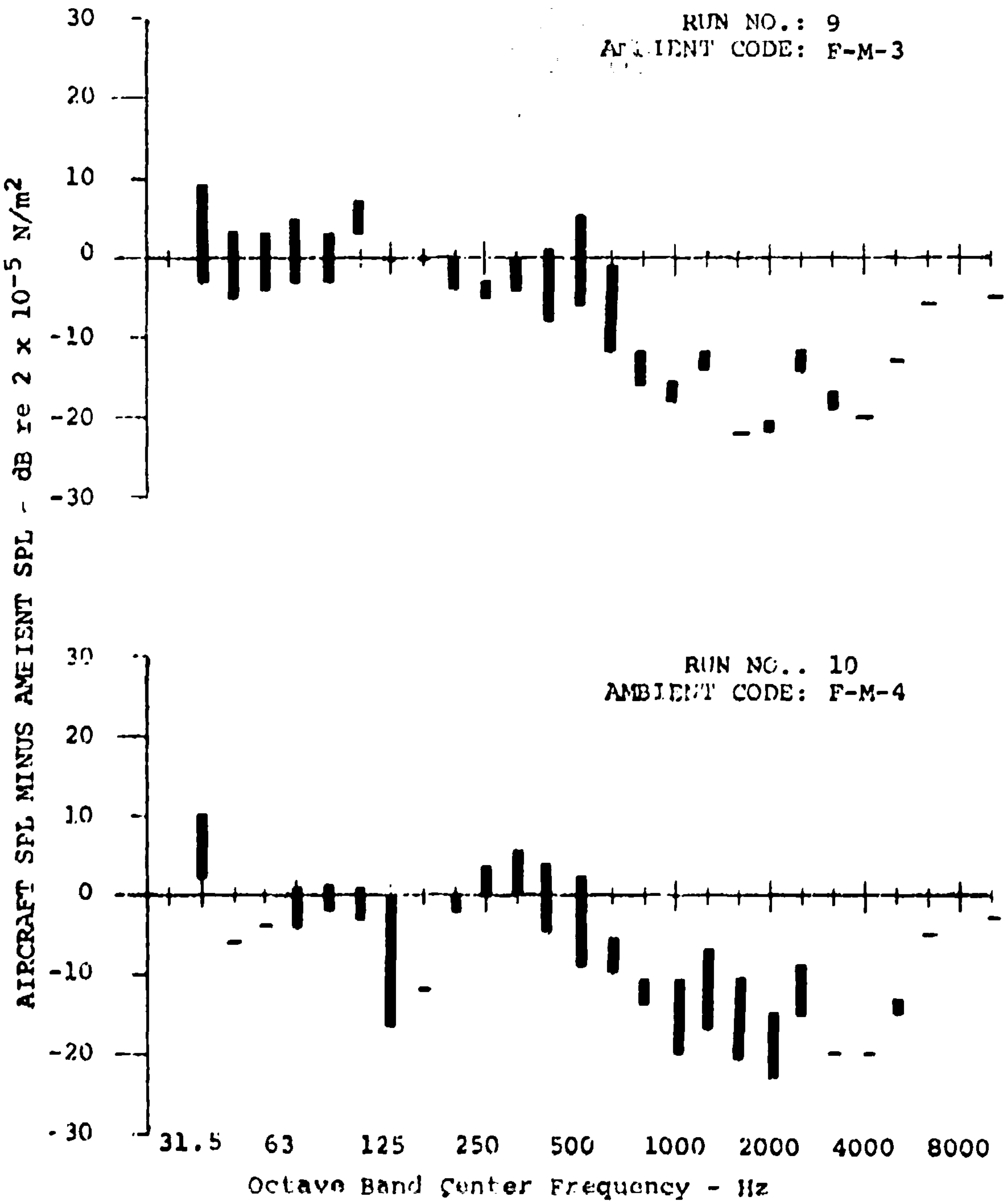


Figure 59. Continued.

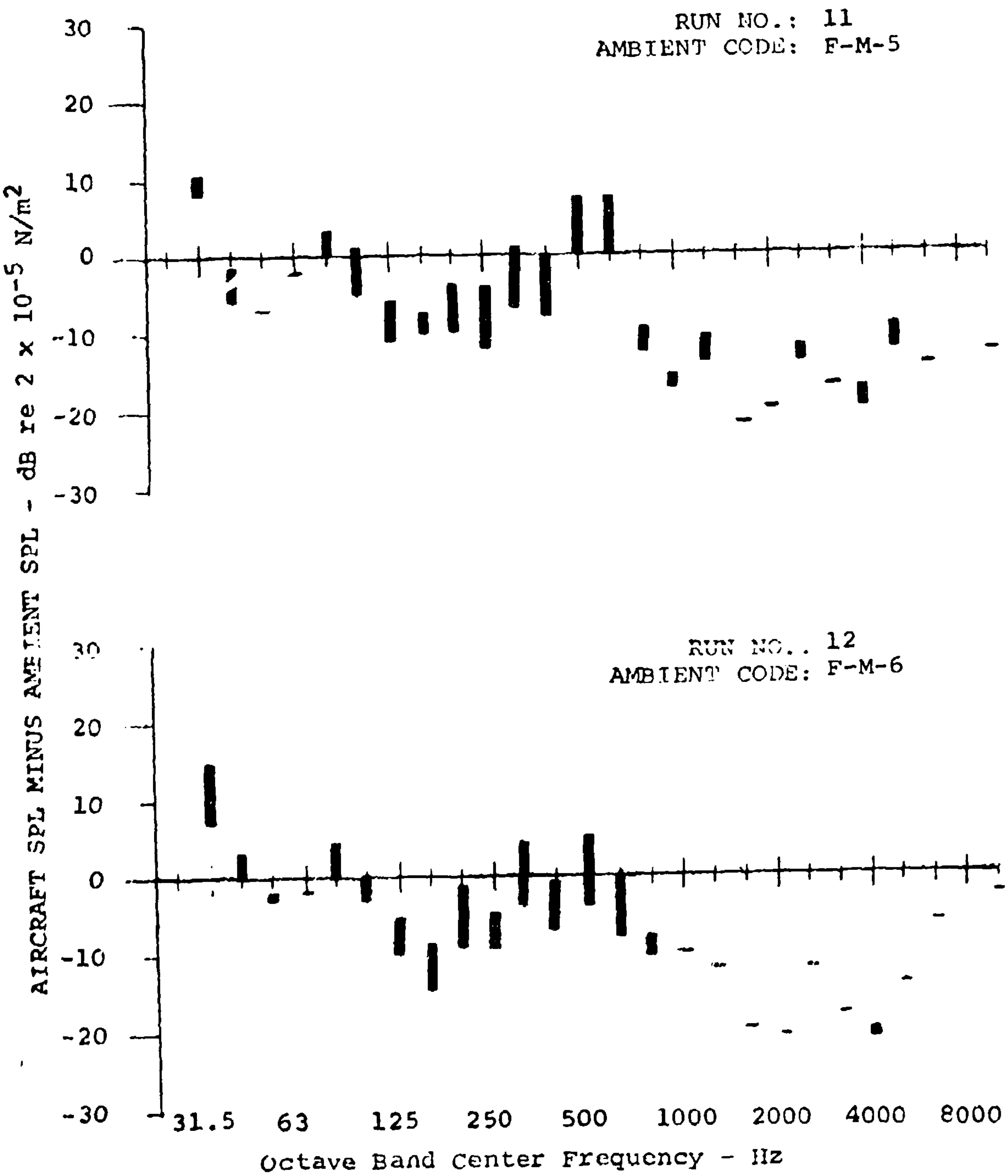


Figure 59. Continued.

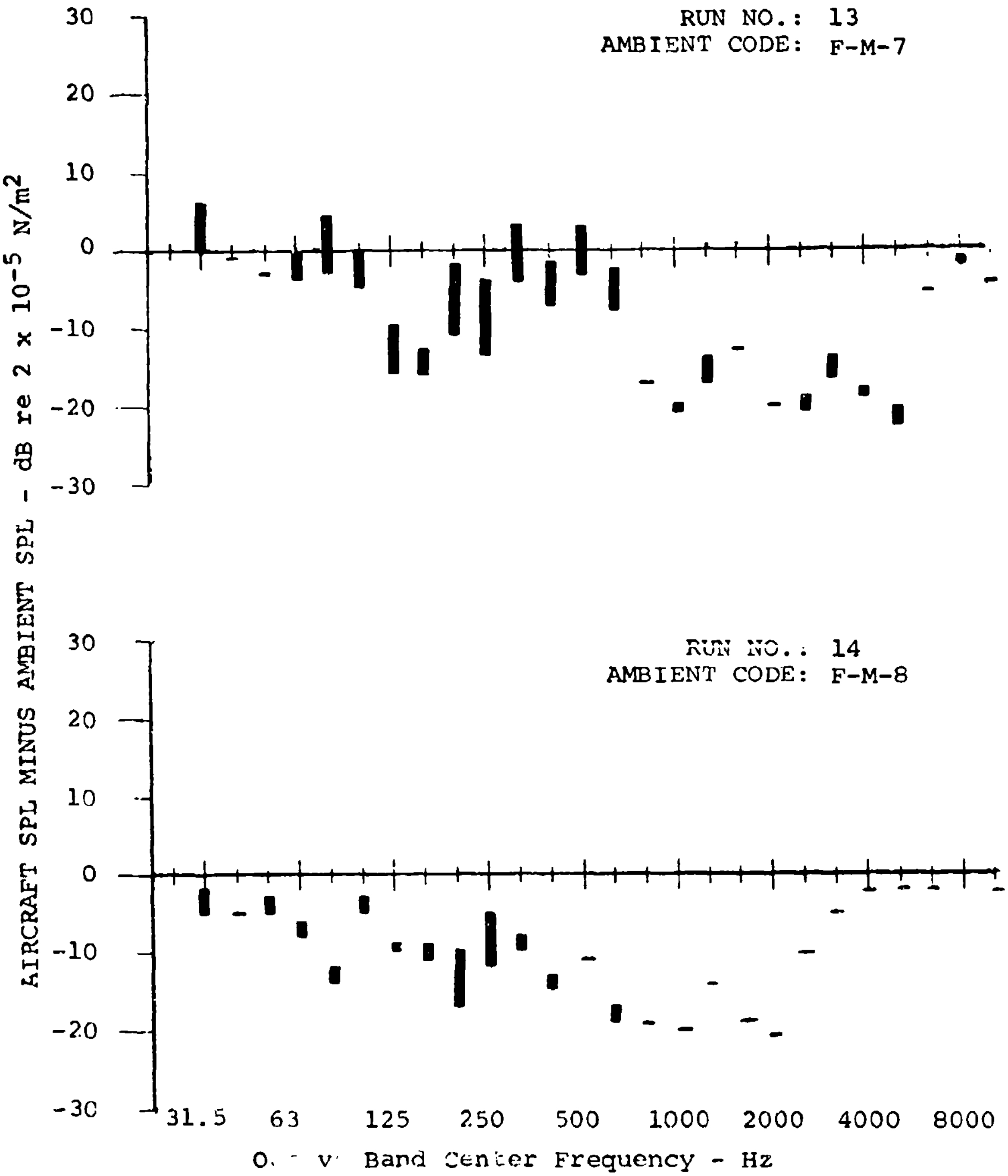


Figure 59. Continued.

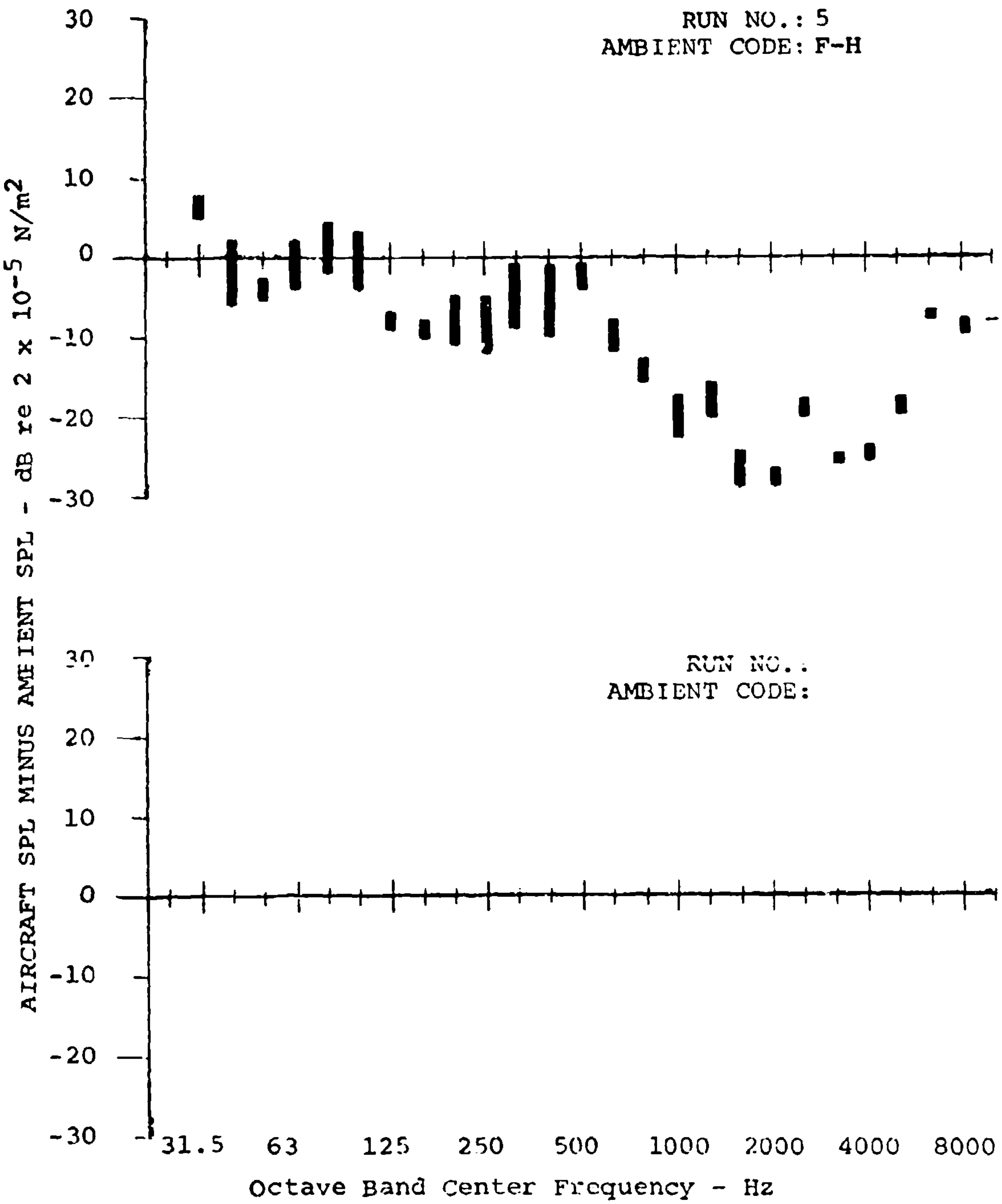


Figure 60. Detection Results With Flat, High-Level Ambient.

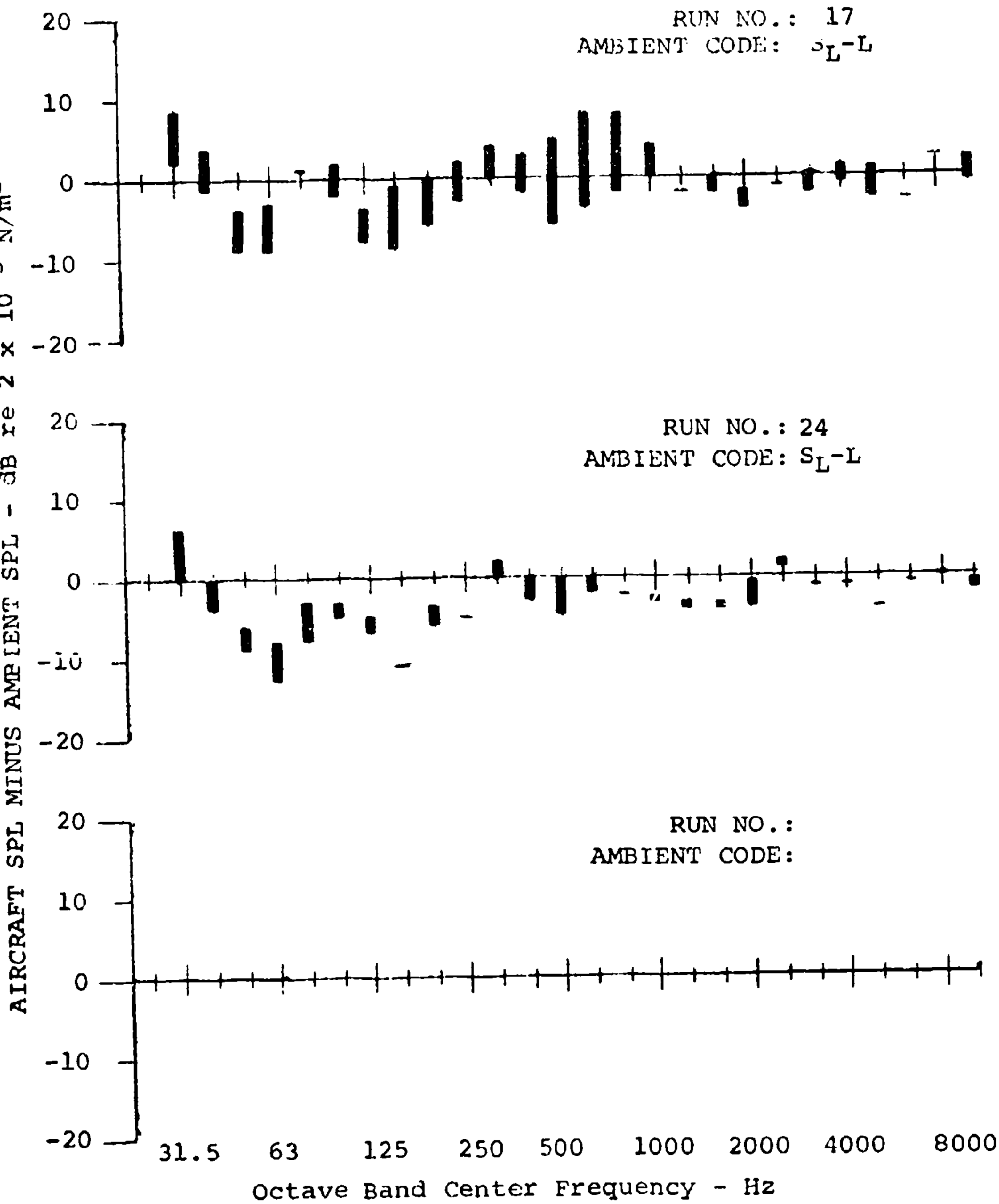


Figure 61. Detection Results With Sloped, Low-Level Ambient.

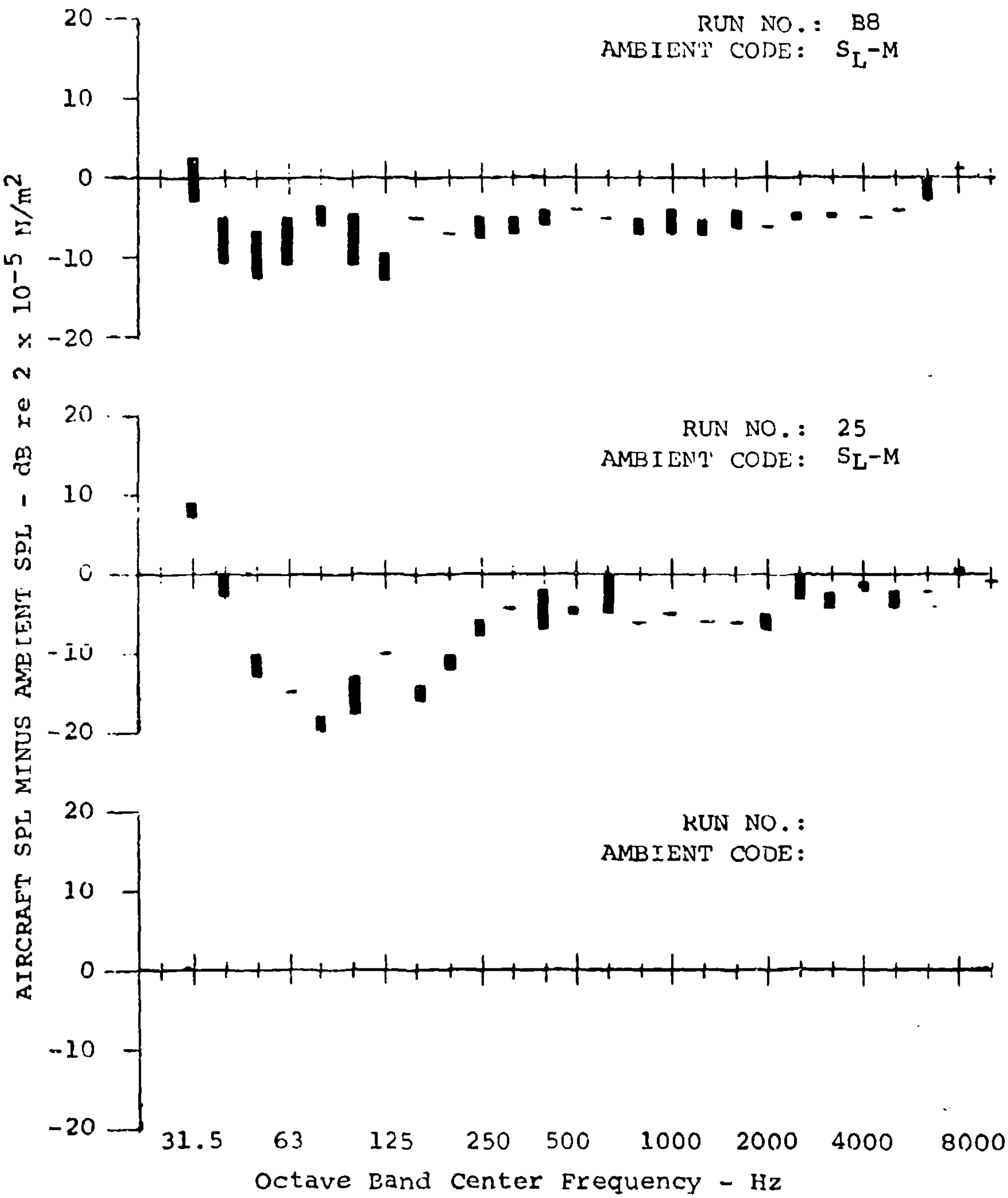


Figure 62. Detection Results With Sloped, Medium-Level Ambient.

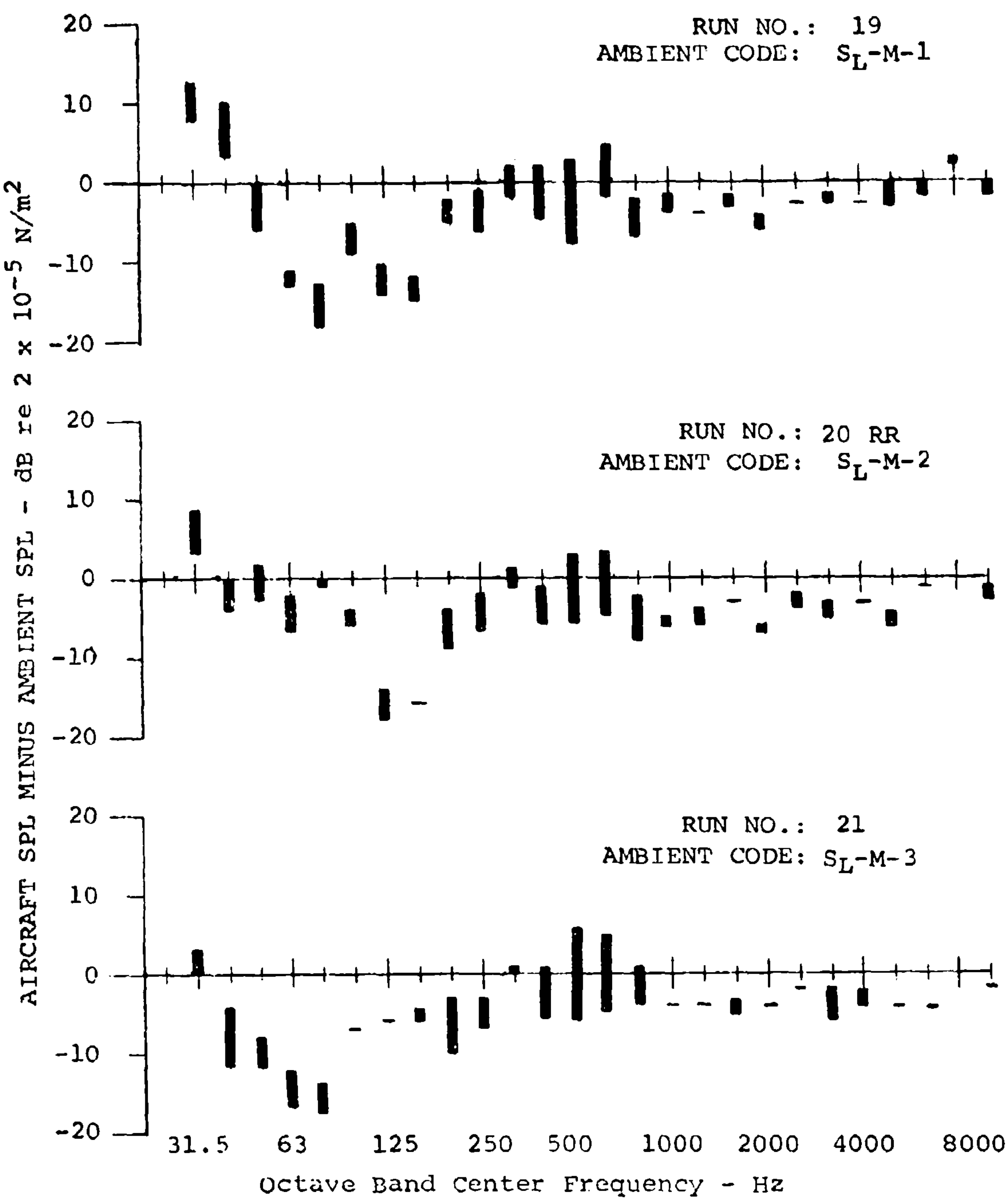


Figure 63. Detection Results With Sloped, Medium-Level Ambient - Specific Octave Bands Removed.

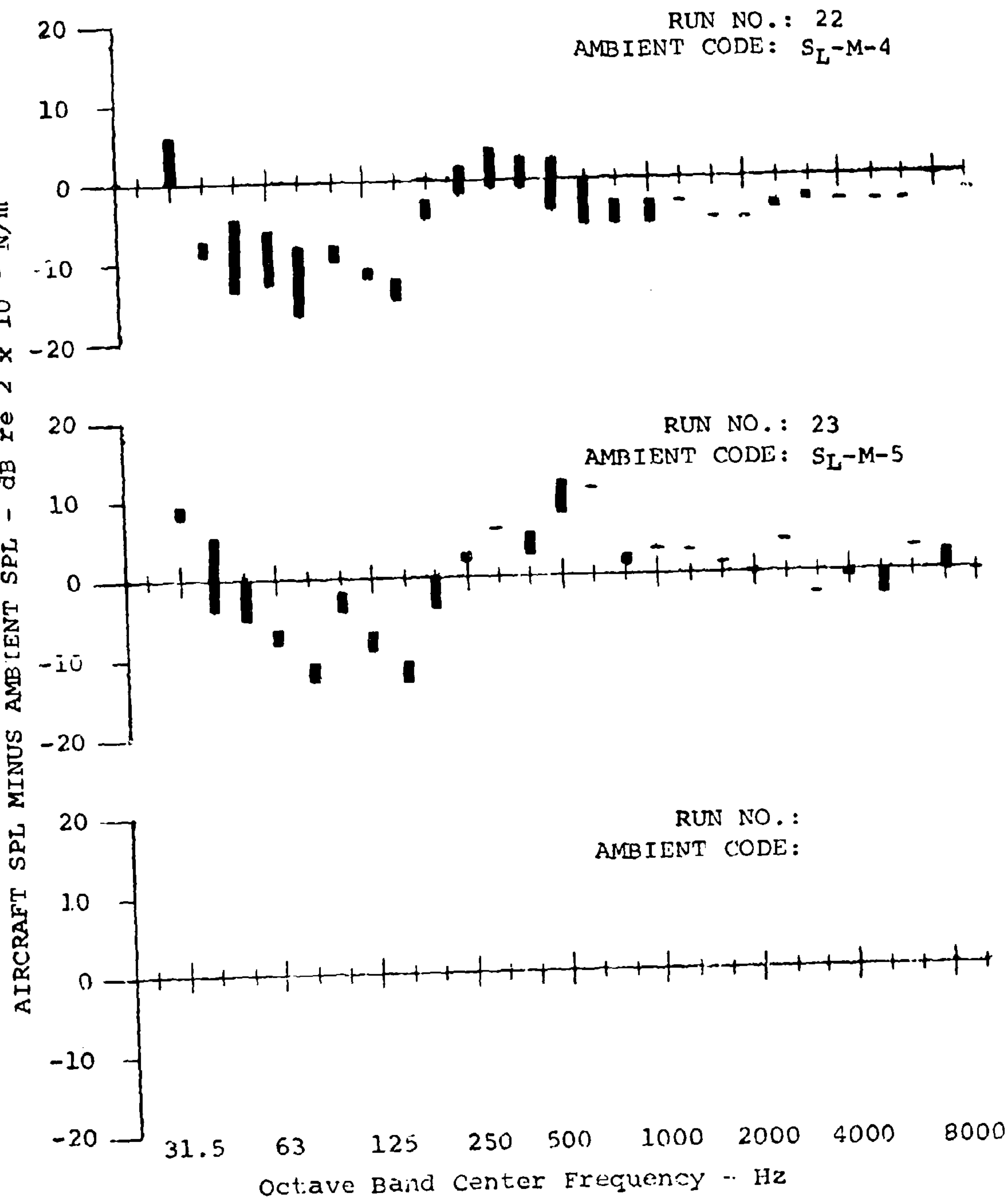


Figure 63. Continued.

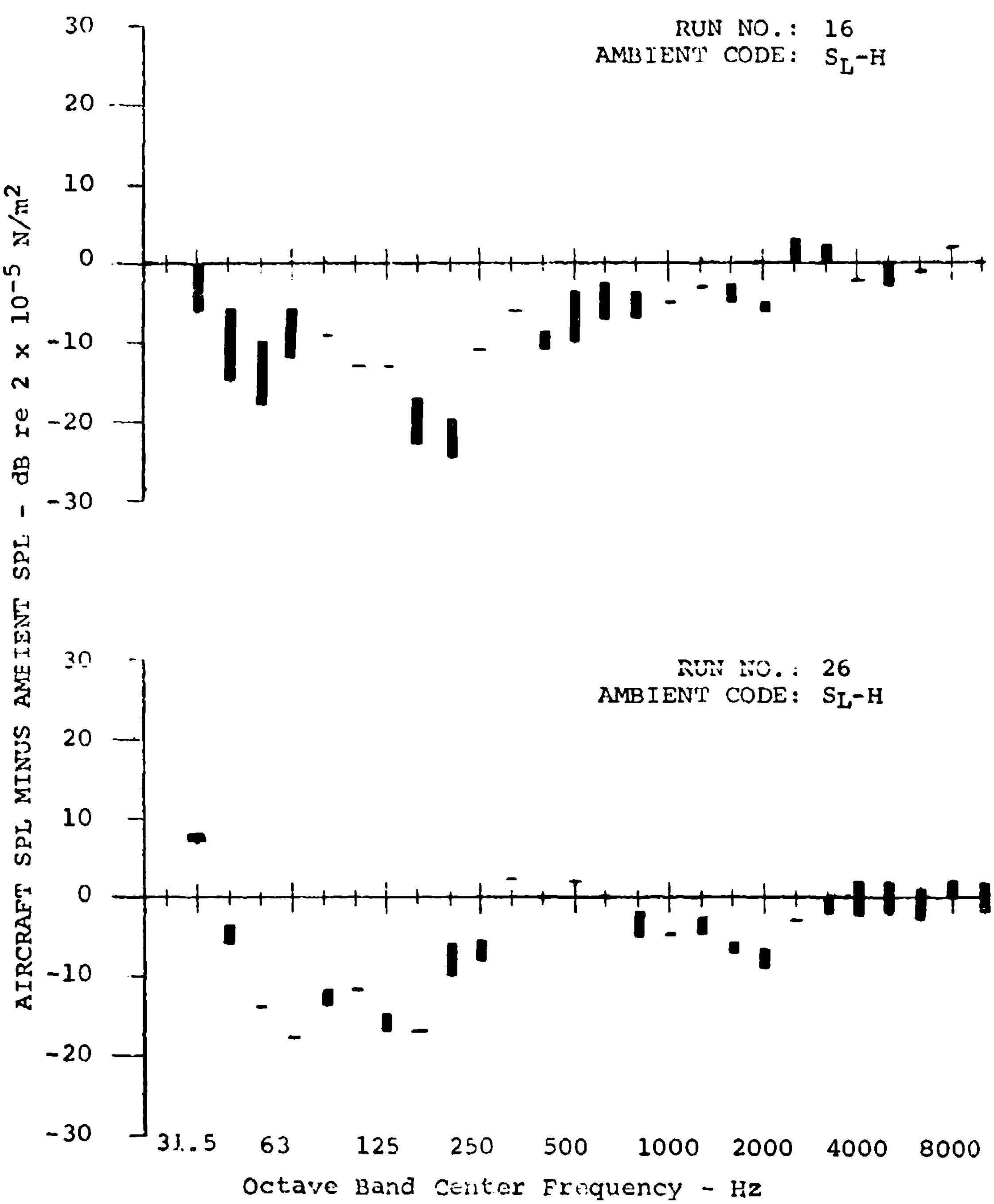


Figure 64. Detection Results With Sloped, High-Level Ambient.

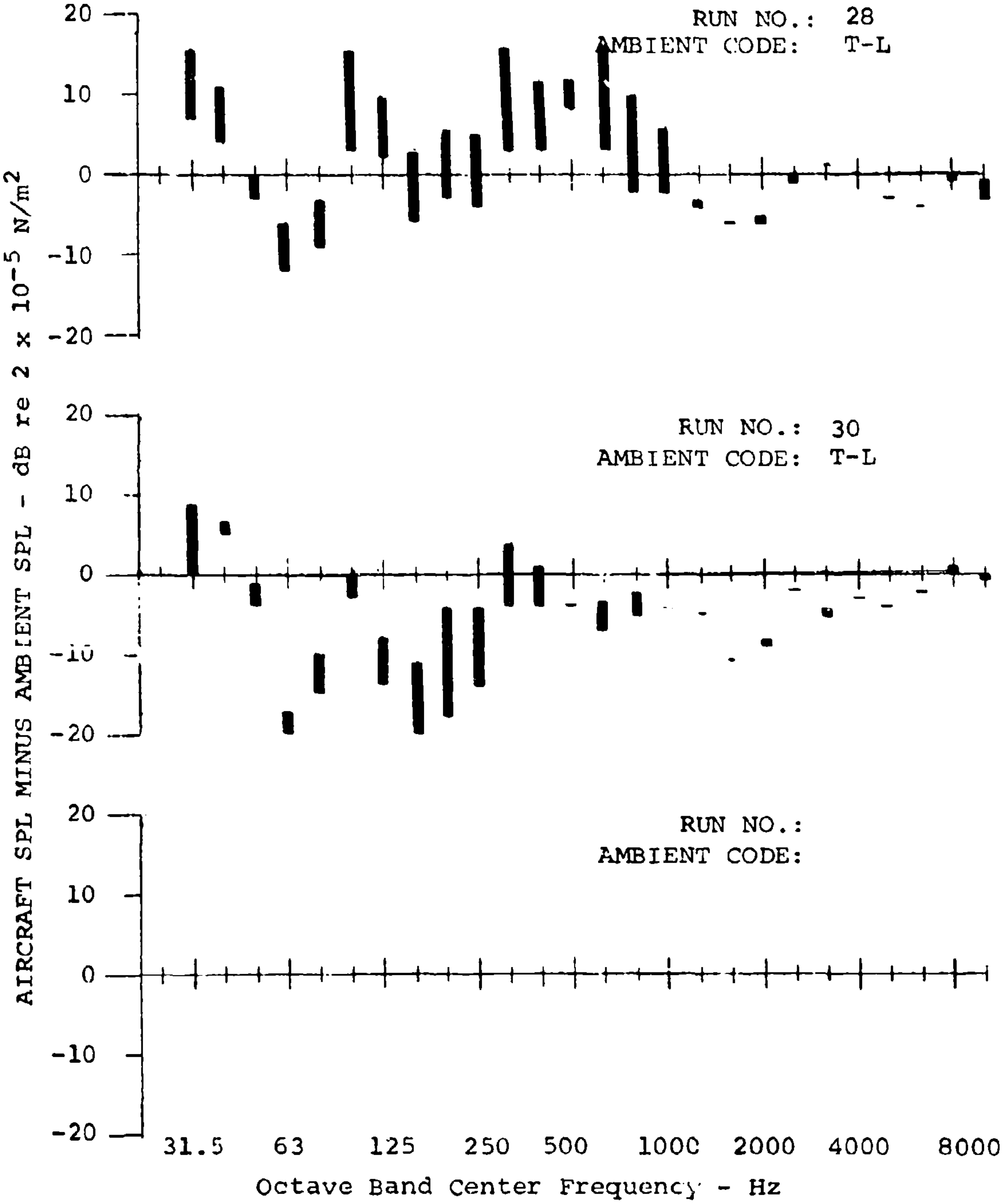


Figure 65. Detection Results With Truck, Low-Level Ambient.

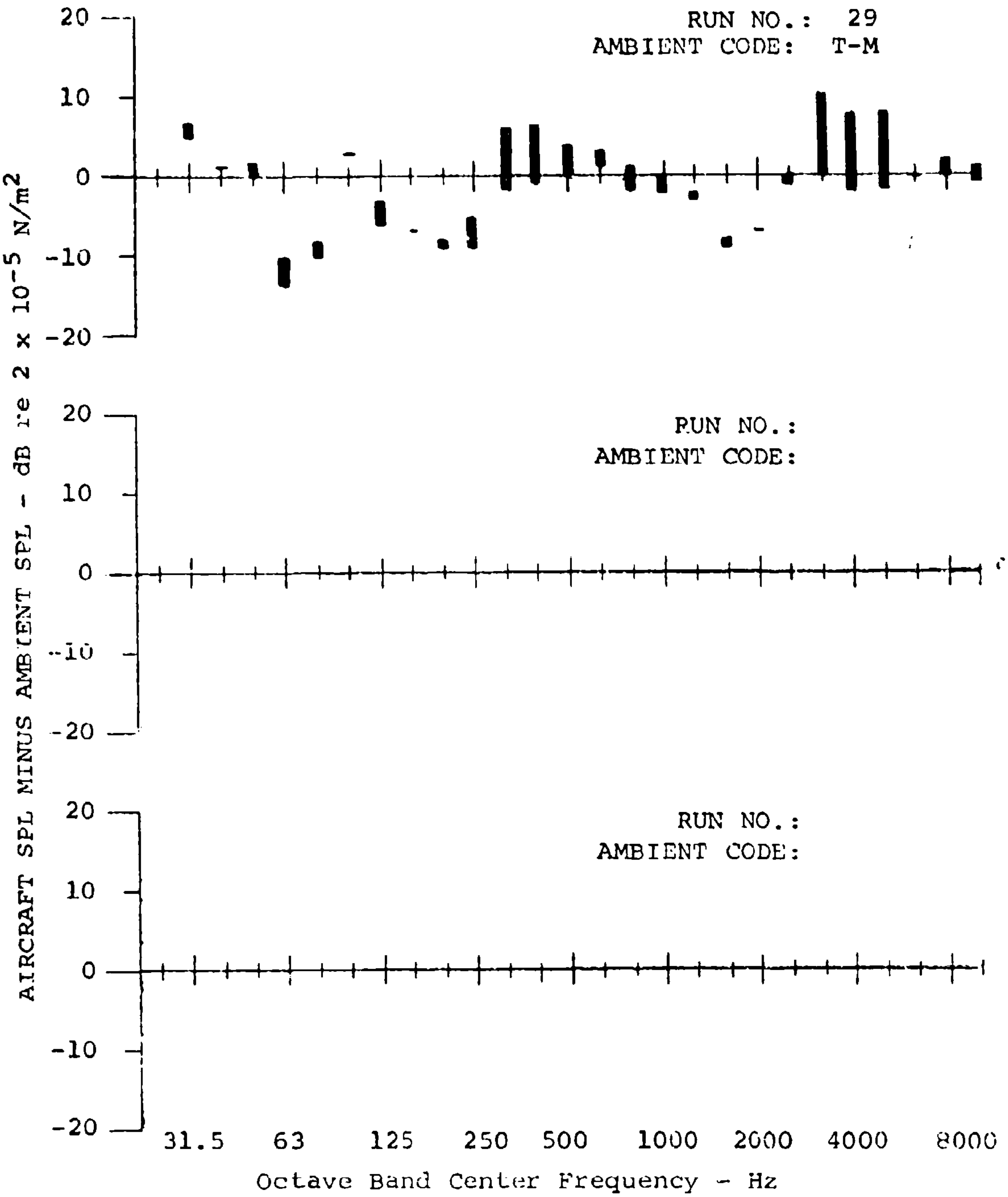


Figure 66. Detection Results With Truck, Medium-Level Ambient.

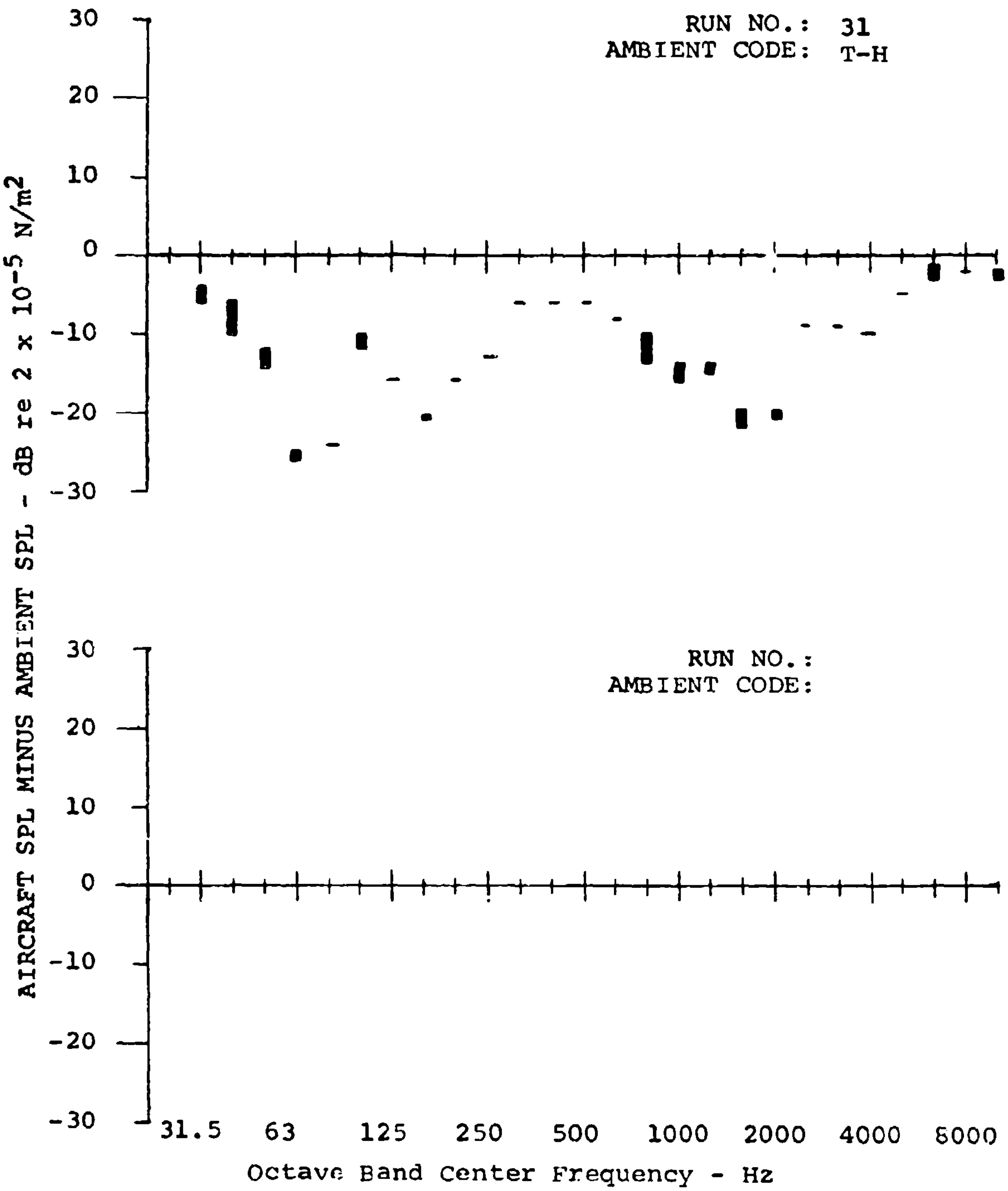


Figure 67. Detection Results With Truck, High-Level Ambient.

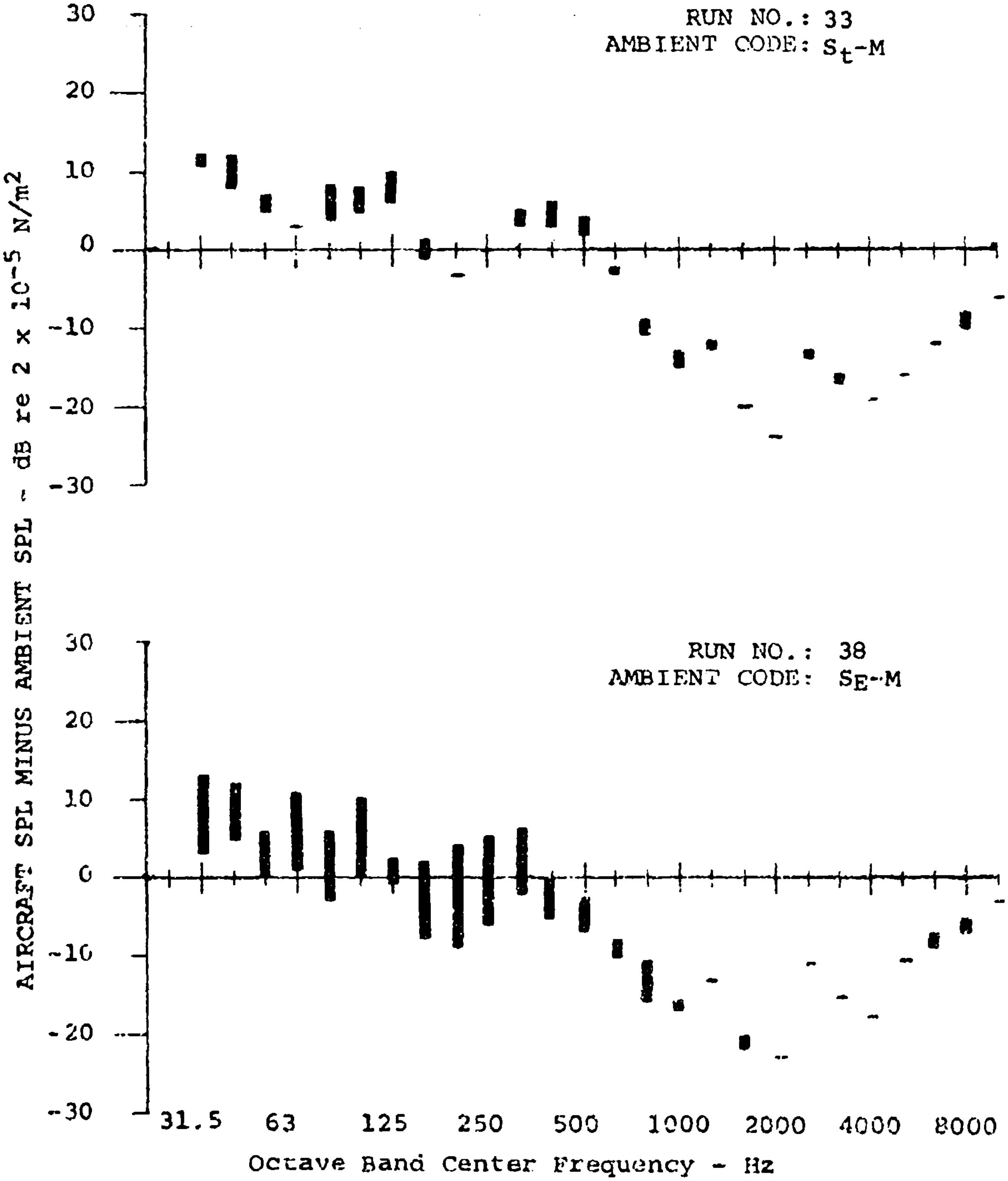


Figure 68. Detection Results With Steady, Medium-Level Ambient.

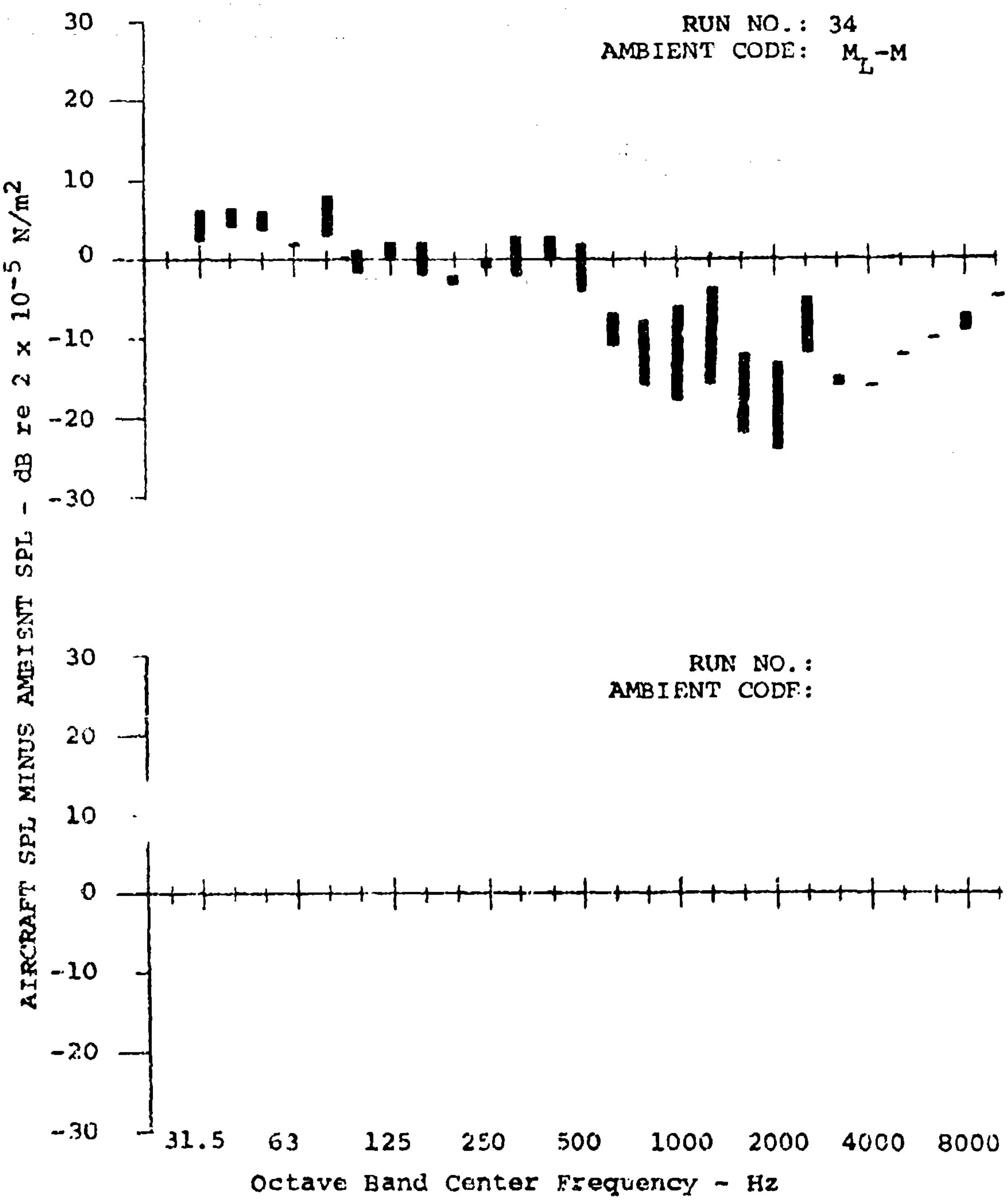


Figure 69. Detection Results With Modulated (Low Rate), Medium-Level Ambient.

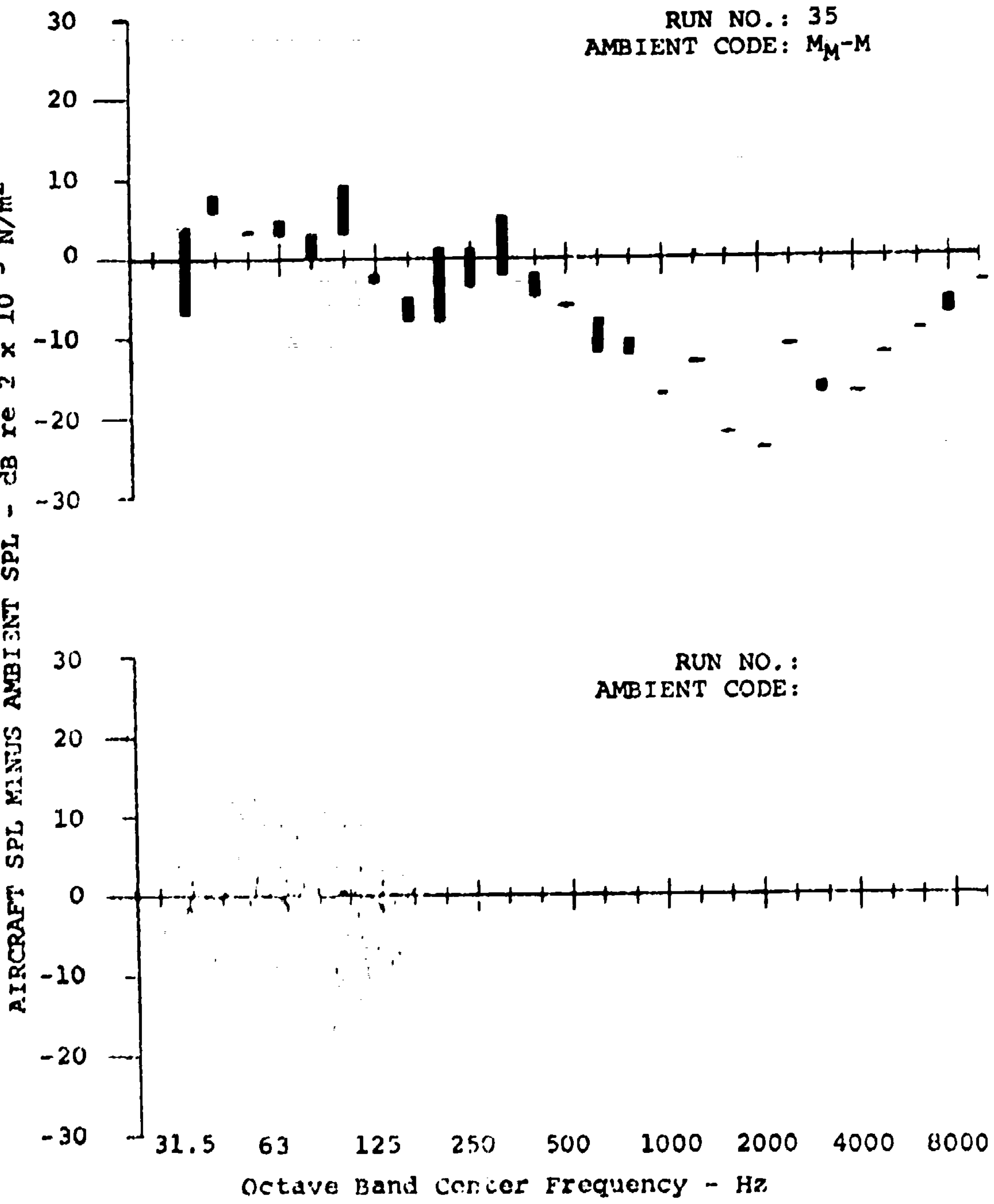


Figure 70. Detection Results With Modulated (Medium Rate), Medium-Level Ambient.

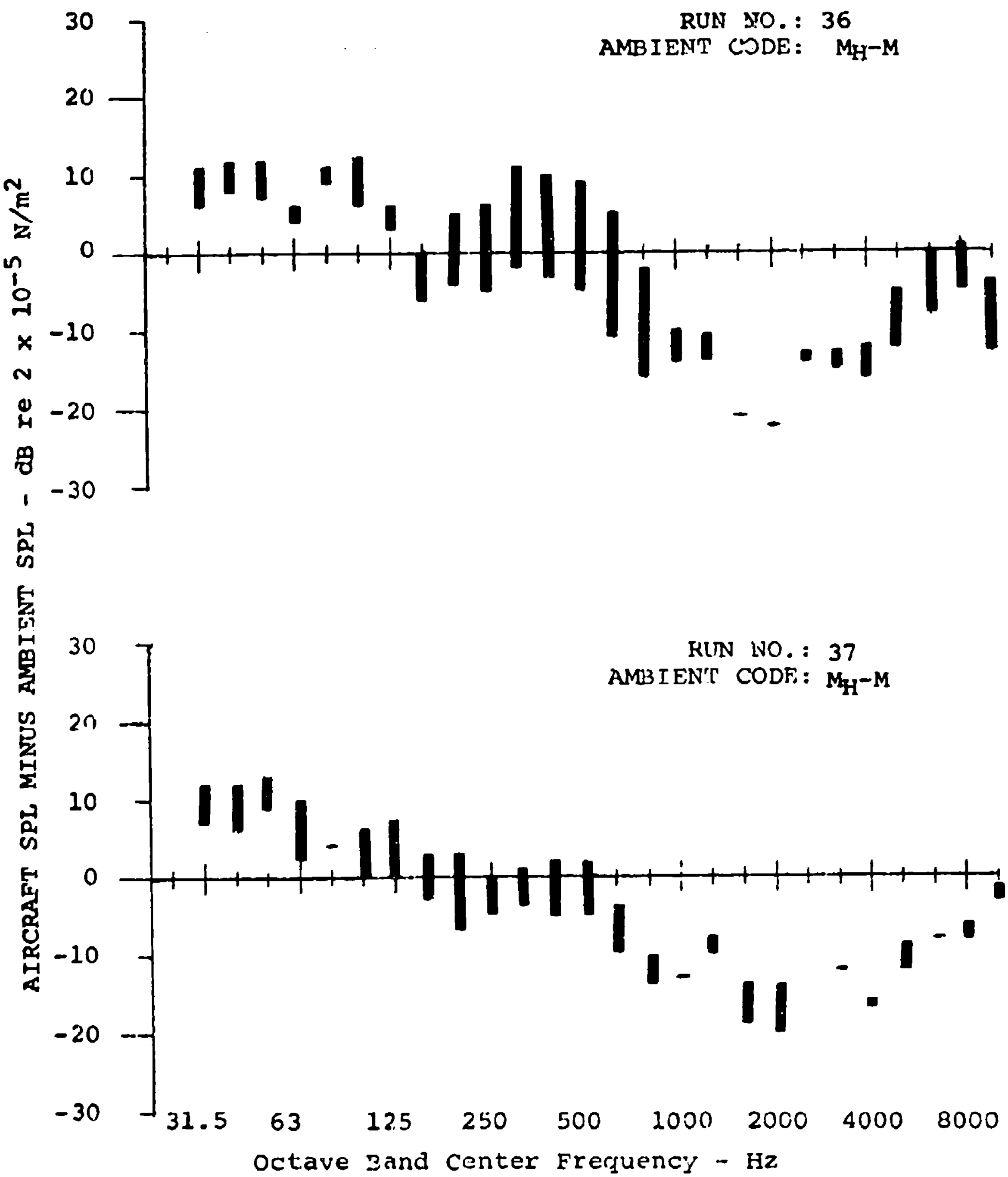


Figure 71. Detection Results With Modulated (High Rate), Medium-Level Ambient.

APPENDIX IV
1/3 OCTAVE BAND HELICOPTER NOISE TIME HISTORIES

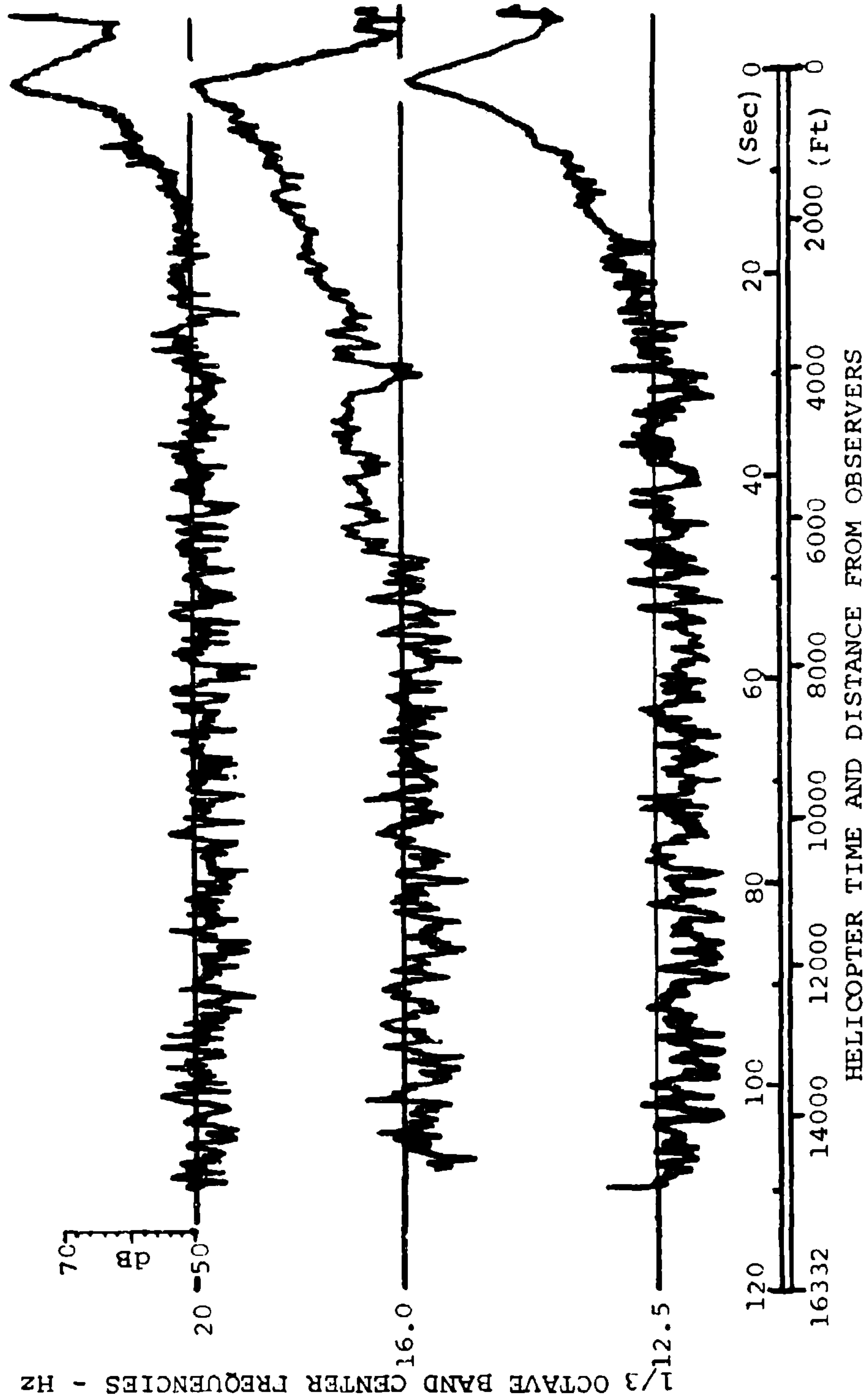


Figure 72. 1/3 Octave Band Helicopter Noise Time Histories (12.5 to 20 Hz).

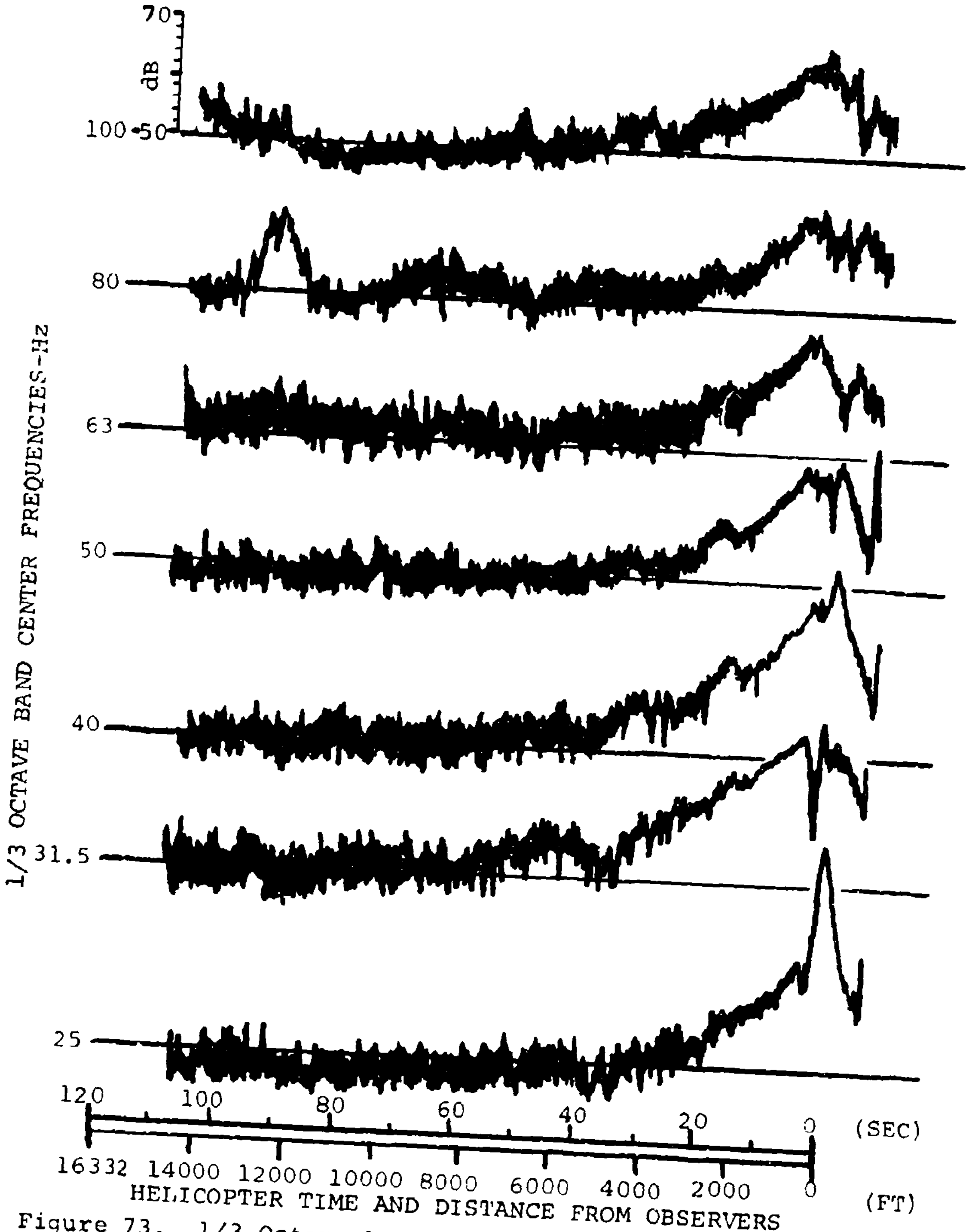


Figure 73. 1/3 Octave Band Helicopter Noise Time Histories (25 to 100 Hz).

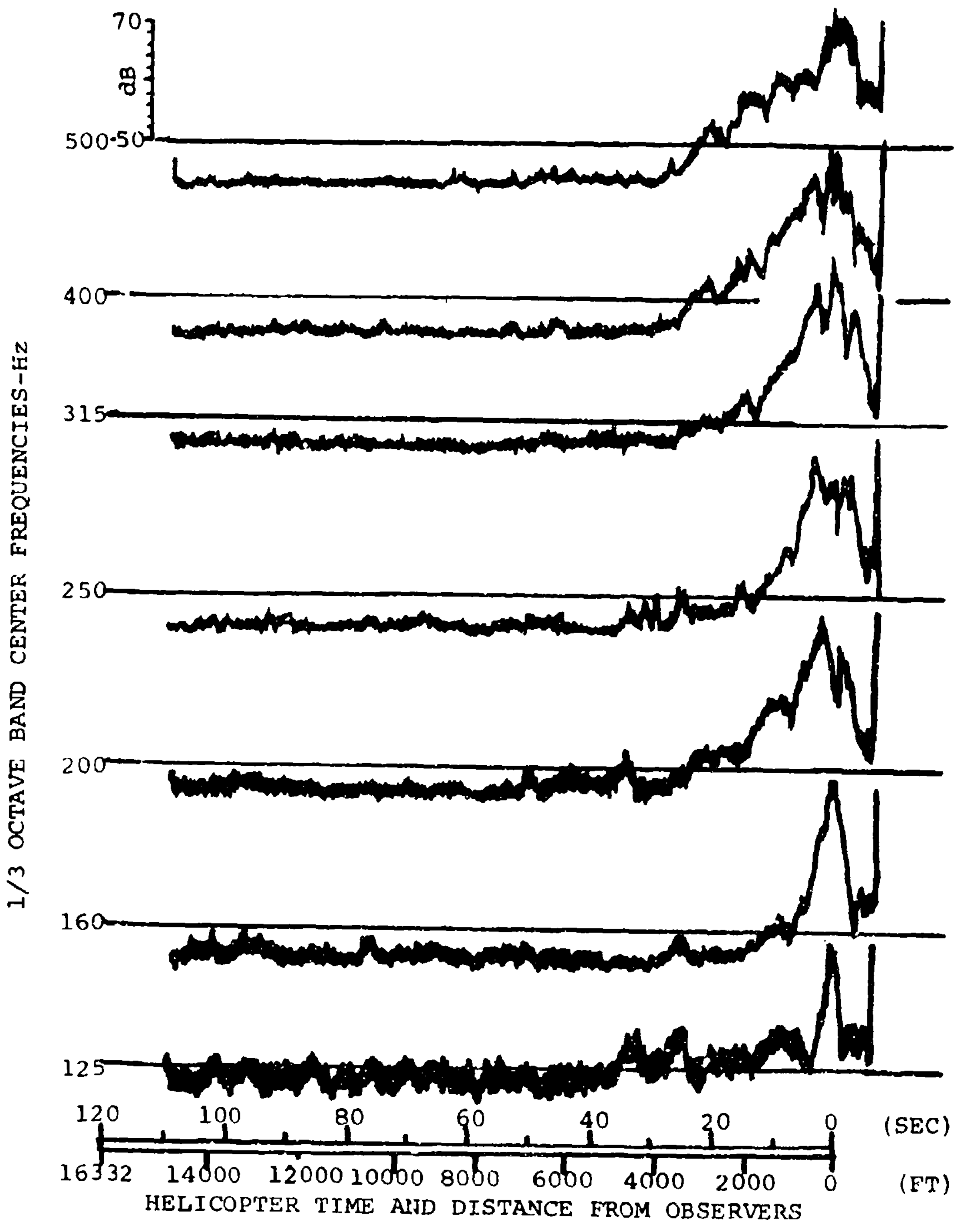


Figure 74. 1/3 Octave Band Helicopter Noise Time Histories (125 to 500 Hz).

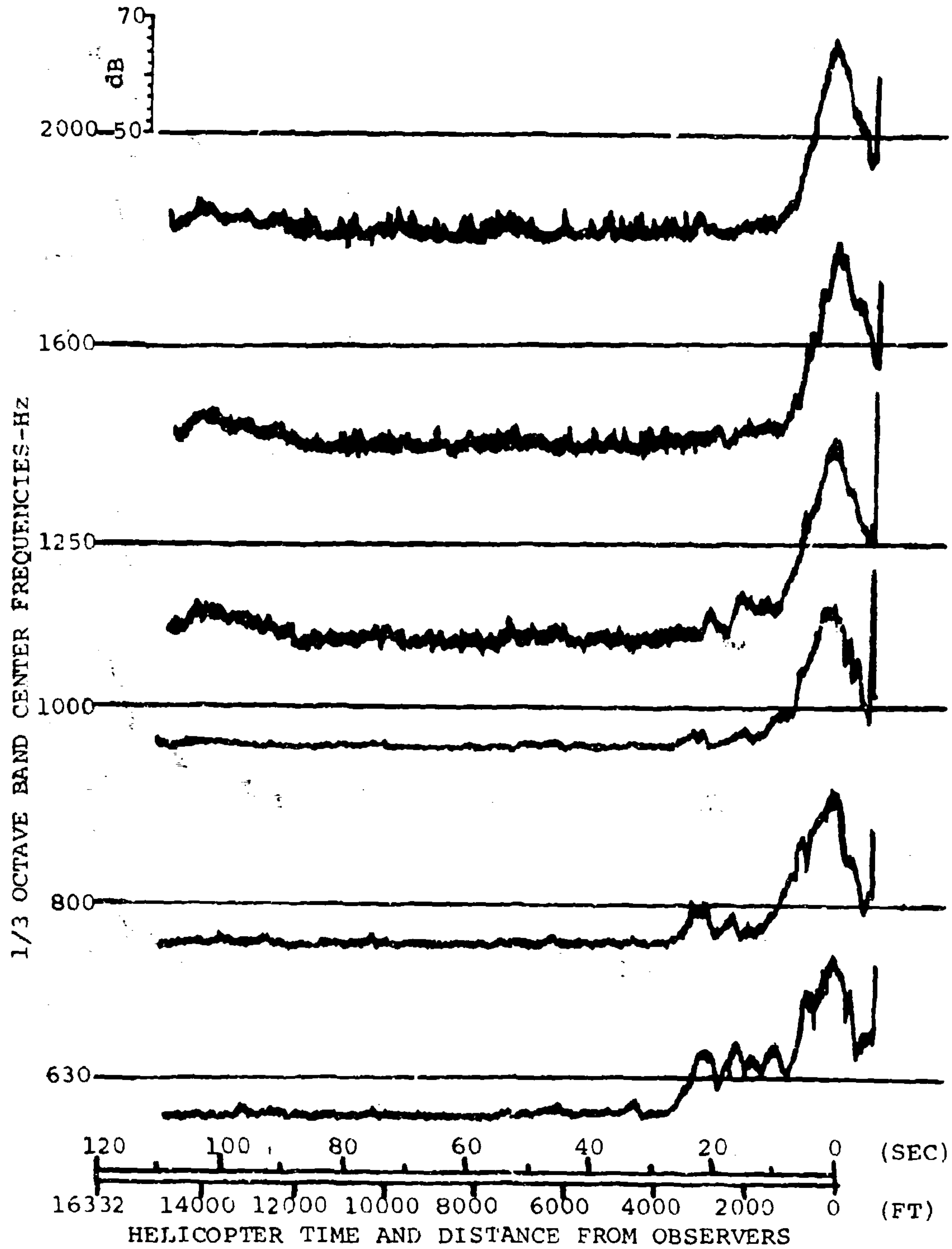


Figure 75. 1/3 Octave Band Helicopter Noise Time Histories (630 to 2000 Hz).

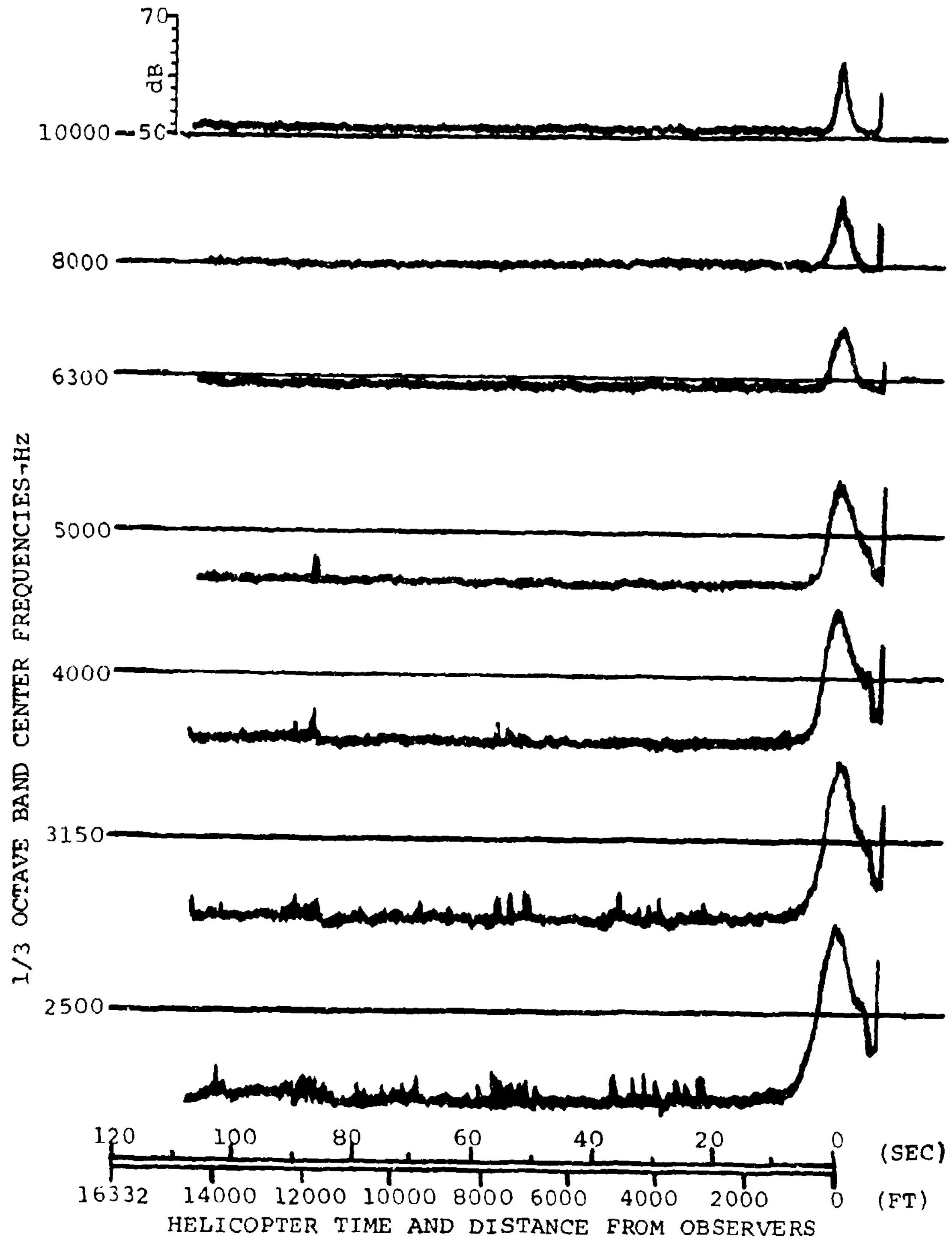


Figure 76. 1/3 Octave Band Helicopter Noise Time Histories (2500 to 10,000 Hz).

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13. ABSTRACT

The report describes a field experiment used to evaluate a theoretical method of determining helicopter aural detection distance. A test program was conducted using a light commercial helicopter, test observers, and supporting acoustic monitoring equipment. Various background ambient noise conditions were used at the observer location. Data was reduced, detection distances were obtained, and comparisons were made with theoretically predicted detection distances.

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